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MEEBS: A MODEL FOR MULTI-ECHELON EVALUATION BY SIMULATION

by

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This thesis describes a simple-to-use, multi-echelon, single-item, simulation model written in SLAM II. The model simulates the operation of Recoverable Items (RIs) at one or more bases and the flow of supporting RIs through a multi-echelon maintenance system. The model can be configured by the user to simulate a system consisting of one to three maintenance echelons with one to six bases. Lateral resupply is also an option. The model uses an (s-1,s) inventory policy. The model calculates several performance measures including operational availability, mean supply response time, and time-weighted backorders. The operating time for each RI is a exponential random variable. The mean failure rate is input by the user and may be different for each base. Each maintenance echelon has a single queue where failed RIs wait for an available maintenance station/server. Each echelon can have any number of servers as determined by the user. The default distribution for repair time is the lognormal but other distributions can be used. The shipping times between all bases and echelons are also determined by the user.

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MEEBS: A MODEL FOR MULTI-ECHELON EVALUATION BY SIMULATION

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requirements for the degree of

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ABSTRACT

This thesis describes a simple-to-use, multi-echelon, single-item, simulation model written in SLAM II. The model simulates the operation of Recoverable Items (RIs) at one or more bases and the flow of supporting RIs through a multi-echelon maintenance system. The model can be configured by the user to simulate a system consisting of one to three maintenance echelons with one to six bases. Lateral resupply is also an option. The model uses an (s-1,s) inventory policy. The model calculates several performance measures including operational availability, mean supply response time, and time-weighted backorders. The operating time for each RI is a exponential random variable. The mean failure rate is input by the user and may be different for each base. Each maintenance echelon has a single queue where failed RIs wait for an available maintenance station/server. Each echelon can have any number of servers as determined by the user. The default distribution for repair time is the lognormal but other distributions can be used. The shipping times between all bases and echelons are also determined by the user.

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THESIS CAUTION

This model was developed in a short time frame. While the author believes the model performs as described, the model has not been fully validated in all possible configurations. Accordingly, all users of this model are recommended to run validation tests for the configuration of interest before accepting the results of the model.

I. INTRODUCTION

This thesis details the development and applications of a logistics simulation model for Recoverable Items (RIs). RIs are items or assemblies that can be made serviceable through maintenance and may be relatively minor items like printed circuit cards or major assemblies like aircraft engines or the aircraft themselves. RIs are normally high cost, low failure rate items. The function of RI models is to either optimize or evaluate a given logistics structure based on the number of RIs in the system and the time required to move them around the system. Many models can perform both optimization and evaluation.

The model described in this thesis is an easy-to-use, single-item, evaluation model. Single-item means the model considers only one type of RI in each simulation run rather than all of the RIs that may make up a weapon system. The model is called MEEBS which is the acronym for Multi-Echelon Evaluation By Simulation. MEEBS simulates a logistics system consisting of up to three echelons and six bases. This is illustrated in Figure 1-1. Multi-echelon means the model can simulate a logistics system with more than one maintenance/inventory level. A base is any geographical location at which one or more RIs are in operation. In MEEBS, each echelon consists of a maintenance facility and a co-located store which holds serviceable RIs.

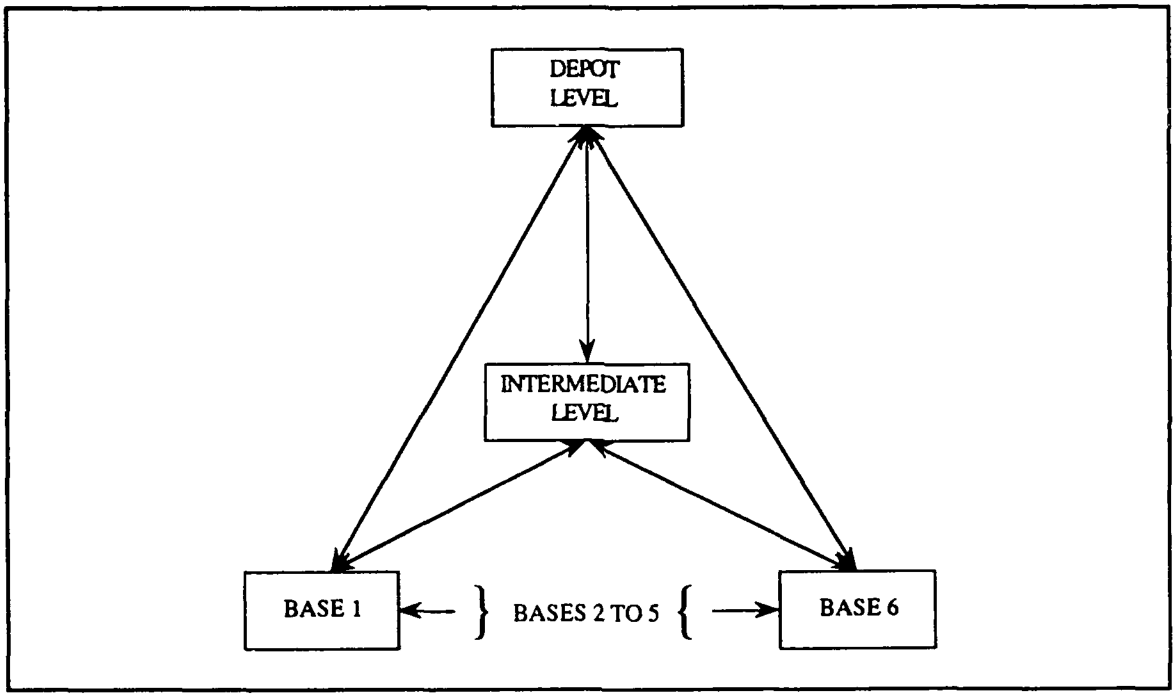


Figure 1-1. The Logistics System Simulated by the Model

A. BACKGROUND

The original area of research for this thesis was the applicability of an optimization model called MATRIARC (Multi-echelon Analysis Technique for Repairable Item Availability and Requirements Computation) to ground radar RIs in the Royal Australian Air Force (RAAF). The RAAF is developing MATRIARC as a possible replacement for its current optimization model. MATRIARC is a modified version of the VARI-METRIC model [Refs. 1 and 2] without the budget optimization function and with the spares allocation part of the model changed to give a higher proportion of the spares to the bases.

The concern with radar RIs was that the failure rate of the RIs may be so low that the assumptions in the model were not valid. However, this author's research indicates that, provided the total number of failures from all radar systems are not so low that the RIs could be classed as insurance items (i.e., items for which there is very little expected demand), the assumptions in the model are valid for radar RIs. For the few RIs that classify as insurance items, the use of criterion functions as proposed by Burton and Jacquette [Ref. 3] or models proposed by Gelders and Groenweghe [Ref. 4] may warrant consideration.

When researching the above problem, it became apparent to the author that, while there is a variety of multi-echelon models available that will optimize the quantity or distribution of spares based on an optimization function that is related to some performance constraint, it is unclear what these performance measures really mean in practical terms and how changes in these measures affect the performance of the system being modeled. The implied objective of most models is weapon system availability for which operational availability is the most meaningful performance measure. However, what the models tend to calculate is time-weighted backorders which is the part of operational availability that is influenced by the supply system. For example, the METRIC family of models use minimization of the total time-weighted backorders as the objective function.

While the various inventory and availability performance measures are related, the relationship between the measures vary depending upon the configuration of the system being evaluated. Another concern is that most analytical models use unrealistic assumptions due to the need to keep the mathematics manageable. For example, the METRIC model assumes that the maintenance capacity is infinite and that lateral resupply does not occur.

Consequently, the author feels that it would be useful to have a relatively easy-to-use simulation model that allows the user to examine:

- the effect of various spares and maintenance policies on the performance of a logistics system;
- how the commonly used performance measures relate to each other and the system being modeled; and,
- the results of the more restrictive analytical models using assumptions that more closely model reality.

B. THESIS OBJECTIVE

The objective of this thesis is to develop a simulation model that will allow the user to examine the relationship between commonly used performance measures and to evaluate the effect of maintenance and inventory policies. The model will also allow other models like VARI-METRIC to be evaluated for a system with limited maintenance resources and with or without lateral resupply.

The significant advantages of using a simulation model rather than an analytical model are that simulation allows far more flexibility in what is actually modeled and it allows a lot more information to be easily obtained. Hence, the author developed the model discussed in this thesis. To the author's knowledge, there is no model currently available that calculates the range of inventory and availability performance measures under finite maintenance capacity and lateral resupply constraints.

C. SCOPE OF THE MODEL

The model developed in this thesis was not limited by the requirement to keep the mathematics manageable because it uses simulation. Rather, the model was limited by the desire to make the model easy to use and relatively quick to execute.

The model reflects reality in several ways:

- The maintenance resources and spares available are finite, and the repair times are random about a given mean. Any desired repair distribution can be used.
- The dynamic environment of the real world in which bases compete for scarce resources, namely spares and repair facilities, is maintained.
- The option of lateral resupply from other bases, which is a common occurrence in most organizations, is available.
- The shipping times for the handling and transportation of RIs between facilities can be different for each base to base combination and each base to maintenance/supply echelon combination.
- The time to failure for the RIs operating at a base is random based on a mean input by the user.
- Whenever a RI fails, the selection of the repair facility is random and is based on a probability input buy the user.

The model also has some limitations:

- The model is a single-item model, which means that if the RI is a subassembly of a weapon system, then only that type of RI is considered at one time rather than all of the RIs that make up the weapon system.
- The model uses deterministic values for the shipping times in order to minimize the number of inputs.
- The repair times for the test stations at a particular echelon all have the same mean and standard deviation but the actual service times used in the model are random variables so the actual times for each service activity is different.
- All RIs at a particular base have same mean failure rate but the mean failure rate at each base can be different.
- Events that normally take only a few hours are assumed to occur in zero time.
- All RIs are assumed to be repairable an infinite numbers of times.

However, many of these constraints can be easily relaxed. One of the significant features of the model is that it is written in SLAM II in a modular format which makes the program very easy to modify. For example, the model can be modified to accept stochastic shipping times by adding an extra field to the SLAM II data array for each base and modifying the code representing the shipping activity by adding a probability density function statement. This would require familiarity with SLAM II, but would take less than an hour to do. A brief outline of how to make other useful changes is given in Chapter IV.

The performance measures calculated by the model are:

- Operational availability and its standard deviation.
- The average number of backorders per 100 days and their average duration in days.
- Service level as measured in terms of fill rate.
- The mean supply response time in days.
- The average time weighted backorders per day.
- These measures are defined in Chapter III.

D. PROGRAMMING LANGUAGE

The principal advantage of simulation is the ability to model the interaction of various dynamic events and activities without artificial limitations. With simulation, it is possible to model almost any activity of any complexity. However, the limitations are execution time and problems with dimensioning the variables and memory constraints.

MEEBS is written in SLAM II, an advanced FORTRAN-based simulation language developed by Pritsker and Associates Incorporated [Ref. 5]. SLAM II is, in part, based on the simulation languages GASP and G-GERT which were also developed by Pritsker and Associates. SLAM II is a very powerful language that is customized for simulation applications where routing and queuing are the major features. The two main advantages of SLAM II are its high level commands and its ability to do all the critical "house keeping" functions associated with maintaining timing and scheduling events. Reference 5 provides a detailed explanation of SLAM II and a good overview of simulation.

E. THESIS PREVIEW

Chapter II provides an overview of current multi-echelon models that are relevant to MEEBS. Chapter III explains the system that the model simulates and how this is implemented using SLAM II. Chapter IV explains how to use the model, analyses some sample results, and discusses further enhancements. Chapter V presents a summary, conclusions, and recommendations.

II. BACKGROUND

This chapter provides a brief review of multi-echelon RI models that are relevant to this thesis.

A. THE OBJECTIVES OF RECOVERABLE ITEM MODELS

Multi-echelon models used today will either optimize or evaluate the performance of a logistics system. Many will do both. Optimization models are designed to achieve one or more of the following:

- determine the optimal inventory levels to minimize the total cost of spares subject to some performance measure constraint;
- determine the minimum inventory levels to meet some inventory performance measure;
- determine the minimum inventory levels to meet some readiness level;

Evaluation models evaluate the performance of a given logistics system with respect to one or more of the above performance measures.

B. THE METRIC MODEL

One of the earliest multi-echelon models was METRIC (Multi-Echelon Technique for Recoverable Item Control) which is a two-echelon, multi-item analytical model. The model was developed by Craig Sherbrooke in 1966 while at The Rand Corporation at the request of the United States Air Force. The model was a departure from most models at the time of its design in that it focused on the cost of the spares rather than the conventional view of balancing holding costs and backorder costs.

1. Objectives

The modes of operation of METRIC are:

- Optimization. The model determines the optimal base and depot spares levels for each RI, subject to a constraint on system investment or performance.
- Redistribution. The model takes a fixed number of spares for each RI and optimally allocates the spares between the bases and depot.
- Evaluation. The model provides an assessment of the performance and investment cost for the system for a given distribution of spares between the bases and depot.

The system objective of the model is:

> to minimize the sum of backorders on all recoverable items at all bases pertinent to a specific weapon system... Take a fixed period of time and add together the number of days on which any unit of any item at any base is backordered. Dividing this number by the length of the period and taking the expected value of the statistic yields a number that is independent of the period length. This is the value we seek to minimize. [Ref. 6:p. 6]

Sherbrooke defined a backorder as follows: "a backorder exists at a point in time if and only if there is an unsatisfied demand at a base level, e.g., a recoverable item is missing off an aircraft". [Ref. 6:p. 6]

2. Assumptions

The main assumptions in METRIC are:

- The inventory policy is a continuous review (s-1,s) which means a replacement item is demanded whenever an item is used. This often referred to as a one-for-one replacement policy.
- The demand is based on a logarithmic Poisson process which is "obtained by considering batches of demand where the number of batches follows a Poisson process and the number of demands per batch has a logarithmic distribution" [Ref. 6:p. 8].
- The mean demand is constant over the period of interest and is estimated by a Bayesian procedure.

- The decision on where to repair a failed item is based on the complexity of the repair and not on the availability of maintenance staff and equipment.
- A failed item enters maintenance as soon as it arrives at a repair facility. In essence, all maintenance facilities have infinite capacity.
- All items are repairable an infinite number of times. i.e., there is no condemnation or attrition.
- Lateral resupply does not occur.
- Some items may have a higher essentiality and hence a higher priority for available funds.

3. Limitations

The major limitations of the model are:

- The assumptions of infinite maintenance capacity and no lateral resupply do not reflect reality.
- The inability to consider attrition may be a limitation depending upon the logistics system being modeled.
- The METRIC model significantly underestimates the number of backorders as the number of spares in the system increase. Reference 1 gives detailed examples of how the error increases as the number of spares increases. Sherbrooke, in discussing the VARI-METRIC model, made the following comments:

> When the METRIC model was developed, it was clear that it understated base backorders. In most cases the error was not large, and the simplicity of METRIC seemed to overshadow the lack of precision. [Ref. 2:p. 311]

C. THE MOD-METRIC MODEL

MOD-METRIC is a modified version of METRIC developed at the Rand Corporation in 1973. The main differences between MOD-METRIC and METRIC are:

- MOD-METRIC allows two levels of parts to be considered: the RI and its components. This feature is often referred to as a two-indenture model.
- Item demand is assumed to follow a Poisson distribution whose mean is a random variable which is distributed according to a Gamma distribution.

D. THE VARI-METRIC MODEL

VARI-METRIC was developed by Michael Slay in 1980 while at the Logistics Management Institute [Ref. 1]. The model uses the same assumptions as METRIC except the demand process is modeled the same as in the MOD-METRIC model: that is, as a Poisson process with the mean estimated using a Gamma distribution. The significant difference between METRIC and VARI-METRIC is that VARI-METRIC algorithms produce results that are more accurate. Sherbrooke, in reviewing VARI-METRIC commented, "Graves shows that in 11% of cases, the METRIC stock levels differ by at least one unit from the optimal results; the VARI-METRIC levels differ in only 1%" [Ref. 2:p. 311].

Stephen Graves developed a simpler algorithm for VARI-METRIC in 1985 [Ref. 2:p. 311 and Ref. 7].

E. THE DYNA-METRIC MODEL

DYNA-METRIC was developed by the RAND Corporation in 1981 for "studying the transient behavior of component-repair/inventory systems under time dependent operational demands and logistics decisions like those that might be experienced in wartime" [Ref. 8:Preface, p. 3]. The model was designed for the US Air Force and is tailored for aircraft. However, it can also be used for other weapon systems like helicopters and tanks. The model:

> ...relates repairable spare parts supply levels and maintenance capacity to the readiness of aircraft by determining repairable requirements that maximize the probability that the Not Mission Capable Supply (NMCS) rate will not exceed a specific value at minimal cost. DYNA-METRIC's representation of the Air Force base-depot supply system closely resembles that of its predecessor, MOD-METRIC... The distinguishing

> feature of the model is its ability to deal with dynamic scenarios...in terms of demands placed on component repair and inventory support. DYNA-METRIC assumes the resupply pipeline distribution is either Poisson or Negative Binomial. All failures are assumed to be repaired. DYNA-METRIC contains a cannibalization option which, when executed, consolidates the existing shortages onto the smallest number of airframes. The model is also equipped with a simulation option that can be employed to address situations where sudden increases in item failure cause demand for repair to exceed the capacity of the available base component repair resources. Otherwise, unlimited repair capacity is assumed. [Ref. 9:p. 8]

DYNA-METRIC assumes a (s-1,s) resupply policy and allows lateral resupply.

F. THE SIMON MODEL

The Simon model [Ref. 10] was developed by Richard Simon in 1971 at the Rand Corporation. The model is a two-echelon model similar to METRIC with the same objective function which is to minimize backorders. The demand process is assumed to be Poisson. The system it models can be described as follows:

> There is a lowest echelon, composed of several independent bases, which is the source of the failures for a particular item. When an item fails, it is inspected at the base and a decision made to repair the item at the base, repair the item at the depot, or forego repair and dispose of the carcasses. Spares may be held at base or depot. If the failed item is to be repaired at the base, a replacement item is supplied from the base spares stock, and the failed item enters the spares stock after being repaired itself. Spare stock at the base is issued on a first in, first out (FIFO) basis and all demands are backordered until filled. If the item is not repaired at the home base, a spare is still supplied from base stock and a replenishment spare is requested from the depot. Demands on the depot are also filled with FIFO priority and backordered until filled. Items which the depot repairs go into spares stock. Other replenishment comes from an exogenous source with an infinite supply. [Ref. 11:p. 1]

The distinguishing feature of this model is that its results are mathematically exact without simplifying assumptions being used. The

Simon model "explicitly uses the distribution of upper echelon backorders while METRIC uses only their expected value through Palm's Theorem" [Ref. 11:p. 5]. Consequently, the model is often used as a reference when evaluating the accuracy of other models. Further work on the model by Kruse [Ref. 11] extended the model to more than two echelons. The main disadvantage of both versions is that they require substantial computer time due to the complexity of the mathematics [Ref. 2:p. 1] and therefore are only used for theoretical or validation tasks.

G. THE AIRCRAFT AVAILABILITY MODEL

The Aircraft Availability Model (AAM) is a multi-echelon, multi-item analytical model developed by the Logistics Management Institute (LMI) for the US Air Force in 1972. The AAM was one of the first models to relate the logistics system in terms of spares to the availability of the weapon system (in this case, aircraft). The model:

> ...relates expenditures for the procurement and depot level repair of recoverable spares to aircraft availability rates, simultaneously producing curves of expenditure versus availability rates... For purposes of the model, an aircraft is considered available if it is not awaiting completion of a resupply action,i.e., repair, replacement, or shipment of a recoverable component. Other circumstances, such as lack of consumable spares and required on-aircraft maintenance, may prevent an aircraft from performing its mission; so the availability rate computed in the AAM is not a complete measure of readiness. None-the-less, it is a reasonable surrogate for such readiness indicators as Mission Capable (MC) rates and a step beyond purely supply orientated measures such as fill rate. [Ref. 12:Executive Summary p. 1]

The AAM uses marginal analysis techniques to select the number of each type of spare to be procured based on the resultant aircraft availability per unit cost. The model assumes a Poisson demand process, an (s-1,s) resupply policy, no lateral resupply, and infinite maintenance capacity.

H. THE SESAME MODEL

SESAME is the acronym for Selected Essential-item Stockage for Availability MEthod and was developed by the US Army in 1980. SESAME is a multi-echelon analytical model that determines "how many of each component to stock at each stockage point in the supply system, taking into account the potential impact of each backordered component on system down time" [Ref. 9:p. 11]. The model operates in one of two modes. In the first mode, it optimizes the spares mix to achieve a stated operational availability at least cost. In the second mode, it optimizes the spares mix to provide the highest operational availability for a given budget. In both modes, it balances the reliability of an item against its cost and buys more of the lower cost, higher failure rate items.

The model assumes an (s-1,s) resupply policy, infinite repair capacity, no lateral resupply, and that the time between failures is exponential.

I. THE ACIM MODEL

ACIM is the acronym for Availability Centered Inventory Model and was developed in 1981 for the US Navy by CACI Incorporated. ACIM is a multi-echelon, multi-item analytical model that maximizes operational availability for a given budget or, minimizes the cost of achieving a given operational availability. This is achieved by minimizing the sum of the time-weighted backorders for all of the items that make up the weapon system. The model considers both repairable and consumable items. The model assumes an (s-

1,s) resupply policy; infinite maintenance capacity; and that the demand follows a compound Poisson distribution. ACIM allows for condemnation of items that are no longer repairable at Intermediate Level Maintenance (ILM) or Depot Level Maintenance (DLM).

J. OTHER MODELS

Reference 9 provides an excellent summary of 17 models used by the military. Reference 13 provides a general overview of the history of RI models and a brief review of several aircraft models.

III. OVERVIEW OF MEEBS AND SLAM II

This chapter describes the logistics system that MEEBS simulates and how this is implemented using SLAM II. Where appropriate, sections in this chapter are divided in two subsections: the first describes the activity being simulated and the second describes the implementation of the activity using SLAM II.

MEEBS is written using SLAM II which is a FORTRAN-based simulation language. Most of MEEBS is written in the network mode. Network is the term Pritsker uses to describe models written using only SLAM II commands. The program is written in a modular format so that it can be easily expanded to include more bases or maintenance levels. The more complex or custom activities like lateral resupply are written in FORTRAN as subroutines. These subroutines are called by the network when required.

A. SYSTEM MODELED

MEEBS models a logistics svstem consisting of any combination of one to three maintenance echelons, and one to six bases, with or without lateral resupply. The model is a single-item model which means it considers only one type of RI at a time. These limits were chosen as a reasonable compromise between the size of the organizations likely to be simulated, the computing time required to run the simulation, and the desire to keep the model easy to use and informative.

Maintenance echelons are levels of maintenance that are distinguished from each other by the complexity of the repair tasks they can undertake.

Normally the echelons are hierarchical in that the simplest (and therefore generally the quickest) repairs are done at the lowest level and the more complex repairs are done at the higher levels. The number of echelons is a function of the failure rate of the RI, the complexity of the RI and its difficulty to repair, and the cost of the test equipment and trained personnel.

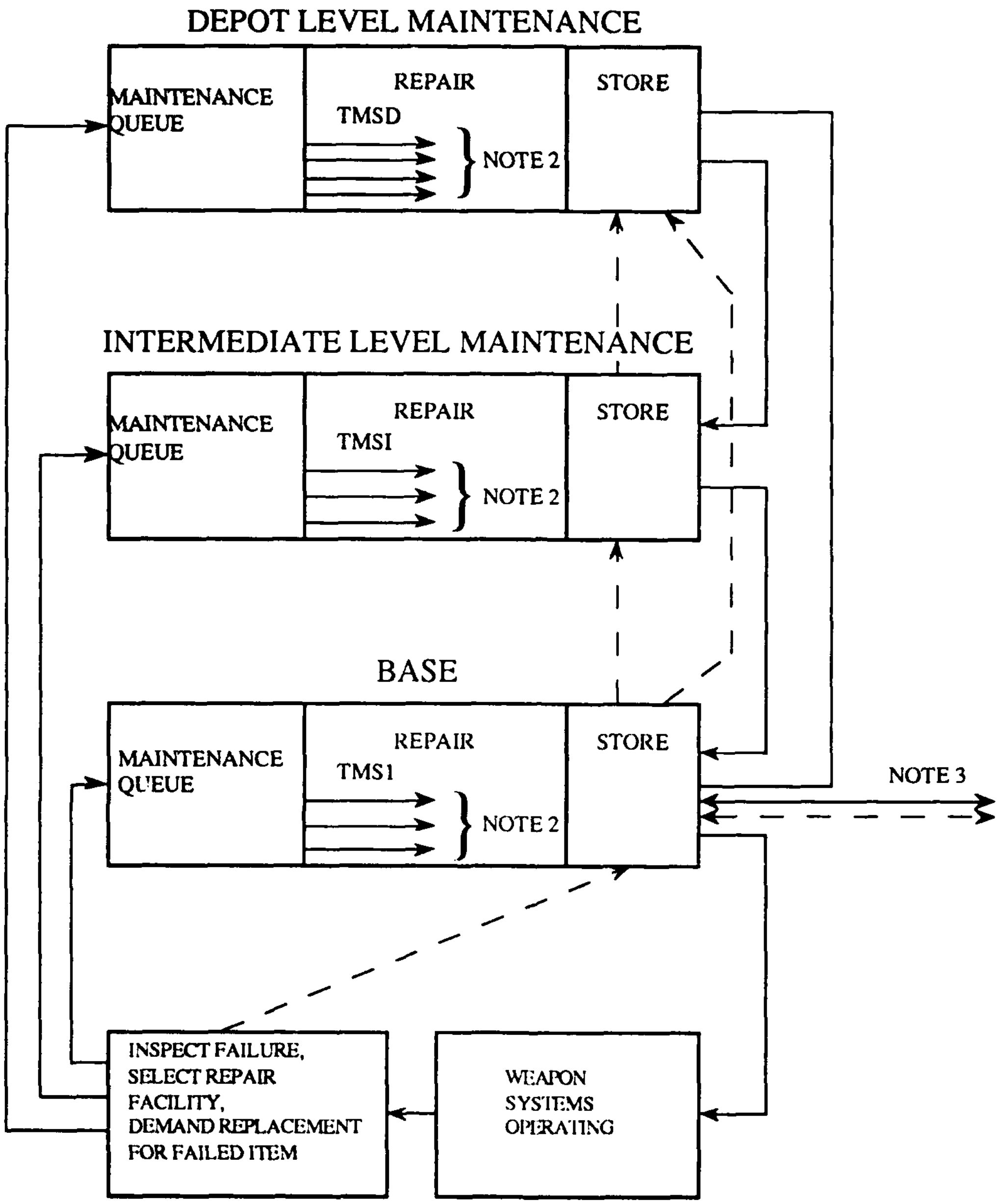
In most military organizations there are three accepted echelons of maintenance. Maintenance performed at the base is referred to as organizational or operational level maintenance (OLM). The next level is intermediate level maintenance (ILM) and the third level is depot level maintenance (DLM). Today, due to the very high cost of test stations and trained personnel, and the high reliability of RIs, there is an increasing tendency to have only two levels of maintenance: operational and depot. This is the case for most ground radar systems in the Royal Australian Air Force. A detailed discussion of the factors to be considered in determining the levels of maintenance for a system is given in Chapter 4 of Reference 14.

In modeling, a system is a circumscribed part of reality that is the object of study or interest. Hence a system is a relative thing. In one situation, a collection of objects may be only a small part of a larger system but in another situation that same collection of objects may be the primary focus of interest and be considered as the system. In this model the primary system is the logistics system for a single type of RI and the objects of interest are the RIs. The logistics system is made up of the following subsystems: the operation and failure of the RIs at each base; the maintenance system that repairs the failed items; the inventory system which processes the demands for spares and stores the serviceable RIs in stores at each base and maintenance facility; and the transportation system that ships the RIs around the system.

The logistics system simulated by the model is as follows. When a RI fails at a base, a spare, if available, is taken from the base store to repair the down weapon system. If a spare is not available, then the weapon system remains down until a spare is available. At the same time, the failed RI is inspected and, depending upon the estimated difficulty of the repair, it is sent to one of the maintenance echelons. The failed RI arrives at the maintenance facility after an appropriate shipping and handling delay and waits in a queue until maintenance personnel and equipment are available. RIs waiting in the queue are allocated to a test station on the basis of first in, first out. In other words, the first RI to enter the queue is the first RI allocated to a station. When a test station is free, the next RI waiting in line enters service. When the RI is repaired, it is put into the store associated with the repair facility and is available for issue. The model assumes a RI can be repaired an infinite number of times.

B. FLOW OF REPAIRABLE ITEMS AND DEMANDS

Figure 3-1 illustrates the flow of RIs and replacement demands/backorders for a three echelon, single base system. The solid lines indicate the flow of RIs and the dashed lines indicate the flow of demands or backorders for serviceable spares.



NOTES:
1. The solid lines indicate the flow of repairable items and the dashed lines indicate the flow of demands and backorders.
2. The number of maintenance stations is input by the user. TMS is the Time to Make Serviceable.
3. Lateral resupply between bases.

Figure 3-1. The Flow of Repairable Items and Demands/Backorders for a Three-Echelon, Single-Base Configuration

At the base level, up to four activities can occur. The RIs operate for a period of time and then fail. When a RI fails, a replacement spare is demanded from the base's store and the failed RI is replaced. At the same time, a replacement is demanded for the spare taken from the store. The failed RI is inspected and sent to a maintenance echelon depending upon the estimated complexity of the repair.

When a failed RI is sent to a maintenance facility, it incurs a forward shipping delay depending upon the handling and transportation time from the base to the maintenance facility. The shipping time is assumed to be zero if the RI is repaired at the base. Upon arrival at the maintenance facility, the RI enters the maintenance queue and waits until a maintenance station is available. When the failed RI is repaired, it is put into the store associated with that repair facility and is available for issue in response to a demand.

The rules and assumptions associated with the above flows and the model performance measures are discussed in the following sections.

C. TIMING ASSUMPTIONS

SLAM II has the capability to operate in any time increments desired by the programmer. MEEBS uses one day as the basic unit of time measurement.

Events that, in reality, would normally take only several minutes or a few hours are assumed to occur instantaneously in MEEBS. The model could be modified to include the actual times for these events as input parameters but this would make the model more difficult to use and provide very little additional insight into the system being modeled. Only if all the maintenance and shipping times were reduced to a few hours, would these instantaneous events have any significant effect on the system's performance. The events that are assumed to occur instantly are: the removal of a failed RI; the repair of the down system if a spare is available at the base store; the time to issue the request for a replacement demand or backorder; the time to move a repaired RI from a maintenance facility to its associated store; and, the time to move a failed RI to a base's operating level maintenance facility.

The user must input parameter values for the following: failure rates, shipping times between the bases and between the bases and maintenance echelons, and repair times at the maintenance facilities. All times are defined in operating days.

D. ENTITIES AND ATTRIBUTES

In simulation terminology, objects like RIs are called entities. Each entity has characteristics that are called attributes. For example, when a RI fails, the base at which it failed and the maintenance facility where it will be repaired can be considered as characteristics or attributes of that RI. In MEEBS, each entity has seven attributes which define some important characteristic of the RI. The functions of the attributes are:

- Attribute 1 defines:
  - the time at which the RI was installed in a system, or
  - the time at which the installed RI failed.
- Attribute 2 records the number of the base at which the RI failed.
- Attribute 3 indicates if the demand associated with the RI is a resupply demand or a backorder.
- Attribute 4 indicates if the demand is from the ILM.
- When a RI fails, attribute 5 records the maintenance facility it is to be repaired at.
- Attribute 6 indicates if lateral resupply has been successful.

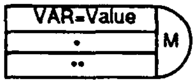
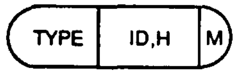
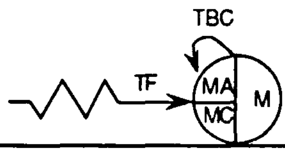
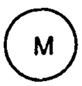
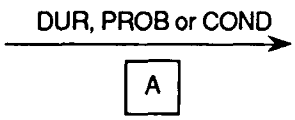
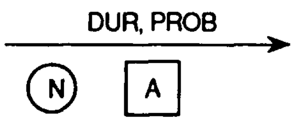
- Attribute 7 records the time a failed RI enters a maintenance queue for repair. When the failed RI is repaired, the difference between the current time and the value of Attribute 7 is the total repair time for that RI. This data is collected for all RIs and output in a summary report.

In MEEBS, RIs (entities) are conserved, hence every RI is assumed to be repairable an infinite number of times. Some models include an attrition rate where, after a certain number of repairs, the RI "wears out" or is no longer repairable and is therefore scrapped. Attrition rates do reflect reality and this feature could have been incorporated in the model. However, attrition considerations were not included because the primary focus of MEEBS is to provide insight into the relationships between failure rates, number of spares, and maintenance and shipping times.

E. SLAM II NETWORK AND THE MODEL

In SLAM II, the system being modeled is represented as a network of nodes, activities and branches through which entities flow. The basic functions and symbols for SLAM II networks are shown in TABLE 3-1. SLAM II functions used extensively in MEEBS are queues and activities. Activities typically represent the use of some resource and are often referred to as servers. Examples of resources are test stations and people. Activities are links between nodes along which entities pass. Service activities are normally associated with queue nodes where entities wait until a server is available. Regular activities can be unconditional, conditional or probabilistic. All three types are used in MEEBS. The time required for an entity to transit a branch can be any time period desired by the programmer and can be random. For example, shipping times are modeled as regular activities connecting bases and maintenance echelons.

TABLE 3-1. SYMBOLS AND DESCRIPTION OF SLAM II NODES AND ACTIVITIES

NODE TYPE/ ACTIVITY	SYMBOL	DESCRIPTION
ASSIGN		The ASSIGN node is used to assign values to SLAM variables (VAR) at each arrival of an entity to the node. A maximum of M emanating activities are initiated.
COLCT		The COLCT node is used to collect statistics that are related to: either the time an entity arrives at the node (TYPE); or on a VARIABLE at the entity's arrival time. An index N may be assigned to the COLCT node to provide a reference number. ID is an identifier for output purposes and H is a histogram specification. A maximum of M emanating activities are initiated.
CREATE		The CREATE node is used to generate entities within the network. The node is released initially at time TF and thereafter according to the specified time between creations of M emanating activities are initiated. The time of creation is stored in ATRIB(MA) of the created entity
EVENT		The EVENT node causes subroutine EVENT to be called with event code JEVNT at each entity arrival. This allows the user to model functions for which a standard node is not provided. A maximum of M emanating activities are initiated.
GOON		The GOON node provides a continuation node where every entering entity passes directly through the node. A maximum of M emanating activities are initiated.
QUEUE		The QUEUE node is used to delay entities in file IFL until a server becomes available. The QUEUE node initially contains IQ entities and has a capacity of QC entities.
REGULAR		A REGULAR activity is any activity emanating from a node other than a QUEUE or SELECT node. The REGULAR activity is used to delay entities by a specified duration, perform conditional/probabilistic testing, and to route entities to non-sequential nodes. If the activity is numbered, statistics are provided on the activity utilization such as the number of active entities and the total entity count.
SERVICE		The service activity is any activity emanating from a QUEUE or SELECT node. The service activity is used in conjunction with the QUEUE node to model single channel queues or queues with N identical servers. Statistics are collected on all service activities. If the activity is numbered, the server status (number of busy or blocked servers) and the total entity count are maintained.

To understand how the functional elements of SLAM II tie together, consider the following two-echelon example. There are three bases and all failures are sent to the depot for repair (There is no intermediate facility). The depot has only one test station. When the RI is repaired, it is sent back to the base it came from. The RI has only one characteristic which is the base it belongs to. A possible implementation of this in SLAM II is as follows. Attribute 1 is set equal to the number of the base that the RI belongs to. When the RI fails, the entity representing the RI is sent to the depot using an unconditional regular activity since all failures are repaired at the depot. When it arrives at the depot, the entity enters a queue node and waits for the test station to be free. When the test station is free, the RI enters the activity and remains there for the time it takes to be repaired. Once repaired, the entity enters a decision node which has three conditional regular activities, one connected to each base. Each activity tests the value of attribute 1 and, if the value equals the number of the base the activity is connected to, the entity is allowed to pass to that base.

F. THE CREATION OF REPAIRABLE ITEMS

At time zero, MEEBS initializes all key variables and creates one entity for each RI in the system. At initialization, the RIs are either part of an operating system at a base or are in a store somewhere in the system as a spare ready to be issued. The number of operating systems at each base, and the number of spares and their distribution are input by the user. The entities are created using the SLAM II CREATE command in a simple loop. Once created, all entities are conserved within the model.

G. SIMULATION OF THE OPERATION OF REPAIRABLE ITEMS

The model assumes that the number of failures over a given time period for the RIs is a Poisson process which:

> ...is loosely described as a completely random sequence of events; an event can occur at any time, independent of when the previous event occurred, but subject to the restriction that the mean rate of the event is constant...A necessary condition for a Poisson process is that the number of events (failures) occurring within an interval of length L is Poisson distributed with a mean FL, where F is the constant mean rate of events (failure rate, hazard rate) of the process...Rejection of the Poisson distribution or rejection of a constant failure rate leads to rejection of a Poisson process. [Ref. 15:p. 5]

A mathematical definition of the Poisson process is given at [Ref. 16:p. 169].

The time between failures is exponential if the number of failures is Poisson. In the model, a pseudo-random number stream is used to select a time to failure from an exponential distribution. The mean of the distribution, which is the failure rate in days, is input by the user for each base. The mean failure rate for each of the RIs at a base is identical but the failure rate at each base can be different.

The actual operation of the RIs at a base is modeled using a queue node and identical servers. In the simulation, a server represents a resource that takes a certain amount of time to perform an activity. In this part of the model, the activity is the operation of the RI, and the length of the activity is the time that the RI is operating. Hence each server represents the operation of one RI and the service time represents its operating time between failure. The operating time for each RI is random, with its mean being either the Mean Time Between Failure (MTBF) or the Mean Time Between

Maintenance (MTBM) depending upon how the user calculates the failure rate that is input into the model.

The service time can be deterministic or based on a probability density function as determined by the user. The exponential distribution is used for the sample runs discussed in Chapter IV as it is a reasonable starting point if the actual distribution is unknown. However, in practice, the user should try to estimate the distribution from operational data and use that distribution or a theoretical distribution that closely approximates it. Theoretical distributions that are available in SLAM II are beta, Erlang, exponential, gamma, Poisson, normal, lognormal, triangular, uniform, and Weibull [Ref. 5:p. 108].

H. SIMULATION OF MAINTENANCE ECHELONS

The maintenance facilities are simulated using queue nodes and identical servers similar to the simulation of the operation of RIs. However, the interpretation is different.

Each maintenance facility has a single queue node where RIs that have failed are sent to wait for a free server. The order in which entities waiting in a queue are processed is on a first in, first out basis. Other queuing sequences are available such as last-in, first-out, or based on a characteristic (attribute) of the failed RI [Ref. 5:p. 116]. The maximum length of the queues is theoretically infinite.

A server can represent a complex automatic test station or a single technician and his tool box or whatever resources are necessary to repair the RI at that level of maintenance. However, all servers connected to a single queue node are identical in that their service times are drawn from the same density function with the same mean and standard deviation. If it was desired to model three different maintenance activities at one facility then three queue nodes and the appropriate number of servers are required. The number of servers at each facility and the service time are input by the user. The mean and standard deviation of each time distribution are input via data arrays at the beginning of the program. However, SLAM II will not accept this form of input for the number of servers and the density functions for the activities. These must be changed in the body of the program by inputting a numeric value for the number of servers and the SLAM II abbreviation for the name for the density function directly into the activity statement. This is a relatively simple, if inconvenient, task. The default distributions in the model are lognormal for the repair distributions and exponential for the operating systems.

I. SHIPPING TIMES

Whenever a RI is moved from one base or maintenance echelon to another, it incurs a delay due to the time taken to prepare the RI for shipment, the actual shipping time, and the unpacking time when the RI arrives at its destination. When a failed RI is sent from a base to a maintenance facility, or from a lower maintenance echelon to a higher echelon, the shipping delay is referred to as Forward Shipping Time (FST). Whenever a RI is sent from a higher maintenance echelon to a lower echelon or base, the shipping time is referred to as Return Shipping Time (RST). Whenever a RI is sent between bases, the shipping time is referred to as Lateral Resupply Time (LRT) as the movement is between locations that are at the same level in the maintenance system. Shipping times generally vary according to the geographical location of the bases and maintenance facilities, and the mode of transportation.

In many organizations, including the RAAF, the requirement to use lateral resupply generally indicates that the support measures put in place to support the operational systems are inadequate. Therefore, lateral resupply is often considered as the last option to obtain a spare for an essential system that is down. This is because lateral resupply often involves substantial financial cost and diverts personnel and resources away from their primary tasks. It also reduces the planned level of protection for the base supplying the spare by reducing the quantity of spares it has on hand to support its own systems. However, there are some systems where the failure rate of the RI is so low and the cost of the RIs so high that the system relies entirely on lateral resupply. Also, lateral resupply can compensate for changes in demand. In certain circumstances, lateral resupply actually reduces the availability of the operating systems at all bases as a significant number of spares are tied up in transit between bases. The benefits and shortcomings of lateral resupply are examined by Sherbrooke in Reference 17.

MEEBS uses deterministic shipping times. This does not reflect the real world in that shipping times generally are random variables. However, the shipping times are generally short and the variation small. For example, consider the case where a shipping time has a normal distribution with a mean of ten days and a standard deviation of one day. Then, on average, 68% of all shipments will arrive between 9 and 11 days and 95% of all shipments will arrive between 8 and 12 days [Ref 18:p. 53]. This variation is not significant when compared to the low failure rate of the RIs, which result in large MTBF values, and their mean repair times. However, if density functions were to be used for the shipping times then a value for the standard deviation as well as the mean would be required and the number of input parameters would increase by 74 for a three-echelon, six-base simulation. This added complexity is not considered warranted for most applications. Chapter IV explains how distributions for shipping times can be incorporated into the model by the user if required.

The notation used in MEEBS is in the form of FSTXY where the first three letters define the type of shipping (e.g., forward shipping time), X defines from where the RI is being shipped, and Y defines the destination. For example, FST1D defines the forward shipping time from Base 1 to the depot level facility.

J. THE (S-1,S) INVENTORY POLICY

The two critical inventory decisions are when to order and how many to order. These decisions involve a trade-off between the costs of maintaining spares in stock and the costs of not having a spare when needed. The (s-1,s) inventory policy is ideally suited to RIs. This is because RIs are generally high cost, low demand items, and therefore only a limited number of spares are procured. The (s-1,s) inventory policy is a continuous review inventory policy which operates as follows:

> ...whenever a demand for an arbitrary number of units is accepted, a reorder is placed immediately for that number of units. This restores the total stock on hand plus on order minus backorders to the (authorized) spare stock level, s. [Ref. 19:p. 1]

In other words, the (s-1,s) inventory policy is a one-for-one replacement policy where a replacement is demanded whenever a spare is taken .rom the store.

K. DEMAND AND BACKORDER RULES

The inventory system modeled is a continuous review (s-1,s) system. Therefore, whenever a spare is taken from a base store, a demand is issued for a replacement spare. If there is not a spare in the base store, the demand for a spare is termed a backorder. The procedures for handling replacement demands and backorders are often different. If the demand is a routine replacement demand (the spare is taken from the store to repair the down system), minimizing the cost of resupply may be more important than the resupply time. If the demand is a backorder, then an essential system is usually down awaiting a spare and the resupply time may be more critical than shipping and handling costs. The procedures for both cases may vary from organization to organization and even within an organization, depending upon the characteristics and criticality of the RI.

For example, if the RI is a relatively inexpensive electronic circuit card such that there are many spares, and the costs and the difficulty of shipping them is low, then a strictly hierarchical resupply system may be used. In this system, the base always places the demand or backorder on the intermediate facility which in turn always places a replacement demand on the depot to replace the spare it just shipped to the base.

If the RI was a very high cost item that is difficult and costly to move, and for which there are very few spares, then the emphasis may be on minimizing the number of shipments. In this case, since the store associated with the maintenance echelon that receives the failed item will eventually receive that item when it is repaired, the policy may be to demand a replacement from the echelon that will conduct the repair. This will minimize the number of units moved. For example, when the failed item is sent to ILM for repair, the base demands a replacement from the ILM store and the ILM store places a replacement demand against the ILM facility rather than demanding a spare from the DLM store. This may be satisfactory for routine demands but in the case of backorders, where resupply time may be the critical factor, the spare is shipped from the source with the shortest shipping time.

The resupply system that MEEBS models is based on the latter scenario where the item is high cost and costly to move. The resupply rules are:

- If it is a routine resupply, the base demands from the echelon that repairs the failed RI. For example, if the failure is repaired at OLM, then the base waits for a repaired RI from its OLM facility.
- If the demand is a backorder, which means the base store is out of stock, the base always tries to get a spare from the ILM store before trying the DLM store. This rule is based on the premise that the return shipping time from ILM is always less than or equal to the return shipping time from the depot. If the ILM store is out of stock, then the base backorders against the DLM store. If the DLM store is also out of stock, what happens next depends upon whether lateral resupply is allowed.
- If lateral resupply is not allowed then the base places a backorder against all maintenance facilities and waits. The first maintenance facility to repair a RI, responds to the backorder. If the serviceable RI is from the base's OLM facility then the backorder against the ILM and DLM are canceled. If the RI is provided by either ILM or DLM then the backorder against the other facility is canceled but the backorder against the OLM remains in case the OLM produces a serviceable RI before the RI from the higher echelon arrives.
- If lateral resupply is allowed, the stores at all other bases are checked and a backorder issued against the base that has the shortest lateral resupply time (LRT). If two or more bases have both spare RIs and the same LRT

then, the base with the most spares responds to the backorder. If all bases are out of spares then the backordering base places backorders against all maintenance levels and waits (as for the case where lateral resupply does not occur).

L. WHEN TO CANCEL BACKORDERS

There are three basic options for cancelling backorders:

- when the demanding base receives the RI;
- when a maintenance level or another base agrees to send a RI in response to the backorder; or,
- issue only one backorder based on knowledge from the maintenance system of when and where the next repaired RI will become available.

The first option is intuitively appealing as the prime objective when a system is down awaiting a spare is to obtain a spare and get the system operational. Therefore, by cancelling a backorder when a RI is received ensures that the system is down for the minimum time as it does not "lock out" any closer sources of supply that may receive a serviceable RI shortly after another, but more remote, source of supply accepts the backorder. It could also result in the demanding base receiving more than one RI in response to its backorder.

For example, if Base 1 issues a backorder at time zero and ILM has no spares but DLM does. The depot dispatches the spare at time zero (based on the assumption that the time to acknowledge and respond to the backorder request is minimal: say, one or two hours) but the RST from the depot to Base 1 is four days. One day later, a RI comes out of maintenance at ILM. The backorder from Base 1 has not been canceled so the ILM store dispatches the newly repaired RI with a RST of two days. One day after, Base 2 has a RI come out of maintenance. Since neither of the RIs from DLM or ILM have arrived at Base 1, the backorder has not been canceled. Hence Base 2 dispatches a RI with a LRT of 1 day. The following day, Base 1 receives RIs sent from ILM and Base 2 and cancels the backorder. However, the RI from DLM is already in transit and therefore it also arrives. In this example, Base 1 ends up with three RIs in response to a backorder for one RI and then has to redistribute any RIs that are excess to its authorized holding level. While this is an unlikely scenario, under the given rule it can happen.

The next option is to cancel the backorder when a a store responds to the backorder. This is the way most inventory systems operate. In the example above, DLM would respond to the backorder. However, the system at Base 1 would be down one day longer than had Base 1 issued the backorder one day later and had the backorder satisfied by the ILM store.

Based on the above examples, the third alternative of issuing the backorder based on knowledge of when and where the next repaired RI will become available is also very appealing. However, how realistic this is depends upon the organization being modeled. If the organization is relatively small or if the down system is extremely critical, then it is likely that there is a central coordinating section that would telephone all potential sources of a spare and, taking into account when the spare is to be available and the associated shipping time, select the source that would result in the minimum down time. On the other hand, if the organization was very large or had a relatively simple set of operating procedures for its supply staff then this option may not apply.

Another factor to consider is that the repair times are not deterministic but rather are random variables from some known probability distribution.

The distribution assumed for the examples in Chapter IV is lognormal with the standard deviation ranging from 10% to 25% of the mean.

In the military, the second scenario where the backorder is accepted by the first supply source that has a spare, is often used for the lower cost RIs like printed circuit cards. The third scenario, where there is a central coordinating office or item manager, is also used in the military for the major, high cost RIs like aircraft engines.

The difference between the backordering procedures only becomes significant if the difference between the longest and shortest shipping times is large and there are a large number of backorders in the sample period. As the aim of MEEBS is to be a general purpose model, the second option was selected as a compromise because it represents a simpler and more general system. Note, however, that option three can be fairly easily added to the current model. This possibility is discussed in Chapter IV.

M. *SIMULATION OF THE DEMAND PROCESS*

As previously discussed, entities representing RIs are conserved in the model. However, entities representing demands are not. Entities representing demands are cloned up to three times as the demand proceeds from the base store up to the depot store. These clones are then destroyed through a combining operation with RIs or by subroutine CANBO. CANBO is short for cancel backorders.

The model uses two queues at each base and at ILM and DLM to simulate the spares store. One queue holds the spares and the other queue holds the demands. This is analogous to a room for the spares and an office for the supply clerk. The inputs to the queues are RIs and demands, respectively. The outputs of the queues are linked by an assembly function.

To illustrate how MEEBS simulates the demand process, consider a simple system consisting of one base and a depot. This is shown in Figure 3-2 using SLAM II symbols.

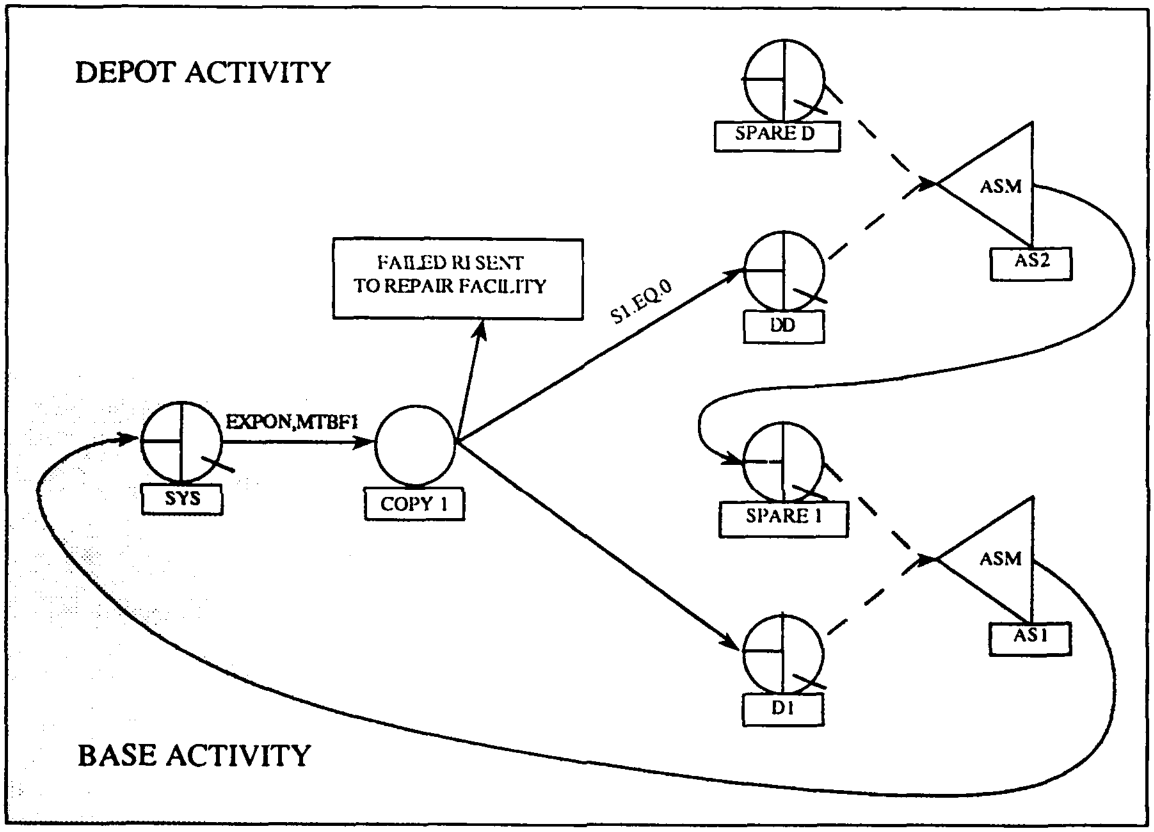


Figure 3-2. Simulation of the Demand/Backorder Process Using SLAM II

At initialization, there are no demands in the system. When a RI fails, a copy of the entity representing that RI is created at a GOON node (COPY1) and sent to the base demand queue (D1) at the base store. This clone of the RI entity is analogous to creating a demand requisition when an item fails. If there is an entity representing a RI in the corresponding spares queue (SPARE1) then the two entities are combined or assembled together at the assembly node (AS1) to form a single entity representing a RI. The RI is sent to the operating systems queue (SYS) and into an idle server representing the operation of a RI.

If there is not a spare in the base's spares queue then another clone representing the demand is also sent to the depot demand queue (DD) along the activity with the conditional statement S1.EQ.0 where S1 is the number of spares in the base store and EQ is equals. This statement will allow an entity to pass if the statement is true. In this example, the depot has a spare so the RI and demand entities are assembled at assembly node (AS2) and sent to the base's RI queue (SPARE1). Now that there is a spare in the base queue, the original demand in the base's demand queue (D1) is combined at the assembly node (AS1) with the entity in the spares queue and sent to the systems queue (SYS) where it commences operation.

N. DEFINITION AND CALCULATION OF PERFORMANCE MEASURES

Commonly used performance measures for systems involving RIs are: the average number of backorders over a given time period; the average duration of the backorders; service level; the Mean Supply Response Time (MSRT); and operational availability (A_O). Traditionally, operational availability is associated with systems readiness while the other measures are associated with the performance of inventory systems.

1. Backorders and Backorder Duration

Sherbrooke, in 1966 in his METRIC model, defined backorders as:

> a backorder exists at a point in time if and only if there is an unsatisfied demand at base level, e.g., a repairable item is missing from an aircraft. Note that this condition can arise even when the base has a positive authorized spare stock for the item, because at a point in time all spares may be in the base repair process or in the depot resupply process. [Ref. 6:p. 6]

This differs somewhat from the conventional inventory definition where a backorder occurs whenever a demand cannot be immediately filled from stock since the latter does not consider whether a system is down. At the base level both definitions are the same. However, at the ILM and DLM levels, many of the demands are "replacement demands" for a spare to replace a spare just taken from the base store.

For example, assume a failure occurs at a base that is authorized to hold two spares and, at the time of the failure, it has two spares in stock. The base issues one spare to replace the failed item and, at the same time, demands a replacement from the ILM store to bring its spares holdings back up to two. However, the ILM store has no spares and therefore places a demand on the DLM store. Using Sherbrooke's definition of backorders, none of the demands are classified as backorders as there is not a system down awaiting a spare. However, using the conventional definition, the demand on the DLM store from the ILM store would be classified as a backorder.

In MEEBS, it is Sherbrooke's definition of backorders that is used. It is used since one of the objectives of MEEBS is to produce results that can be compared to analytical models, most of which used Sherbrooke's definition of backorders.

The model calculates the number of backorders per 100 days by using a global variable in a SLAM II ASSIGN statement at each base to count each backorder as it occurs. At the end of the sample period, the global variable is called into subroutine STATS and divided by the number of days in the sample period. Normally backorders are dimensioned as the number of backorders per year or per quarter. In the model, the dimension of backorders per 100 days is used because the number of working days in a year can vary as the model assumes every day is a working day. Therefore, if the RIs in the system being modeled operate every day of the week then the number of days in a year, from the model's view point, is 365. If the RIs only operate five days per week then the number of working days per year are 260. Rather than try and factor all possible combinations into the model, the dimension per 100 days is used and the user can scale the results accordingly.

The average backorder duration is the total time it takes to satisfy all backorders, divided by the total number of backorders. The model calculates it as follows. Using a SLAM II ASSIGN statement, Attribute 1 is set equal to the time at which the RI failed. When a spare arrives at the base store in response to the backorder, the time previously stored as Attribute 1 is subtracted from the current time. The resultant time difference is the time it took for the backorder to be satisfied. The cumulative total is stored using a global variable as described above. All these operations are performed using SLAM II ASSIGN statements.

2. Time-Weighted Backorders

Time-Weighted Backorders (TWBO) is the number of backorders in a given time period multiplied by the average duration of the backorders. This is the supply system's contribution to operational availability. The definition of operational availability is presented later in this chapter. As mentioned in the previous section, global variables are used to store the number of backorders per sample period and the cumulative time those backorder are outstanding. The subroutine STATS divides the total time the backorders were outstanding by the number of days in the sample period to produce a value for TWBO that is dimensioned in backorder-days per day. Normally, TWBO is dimensioned in backorder-days per year but, as explained in the previous section, the time frame per day is used to overcome problems with the number of working days per year.

3. Mean Supply Response Time

The MSRT is simply the time it takes, on average, between when a spare is demanded and when that spare is supplied. This differs from the average duration of backorders in that the time to fill all non-backorders, which is zero, is included in this average. MSRT is equal to TWBO per day divided by the number of demands per day.

4. Service Level

Service level is often used as a performance measure for an inventory system. Tersine makes the following comments:

> There are several ways to measure service level. It can be computed on units, dollars, transactions, or orders. It is frequently defined for some specified time period when orders are normally filled from stock. It may be specified in general as the percentage of demands filled 'on time'; that is, within a specified time period after receipt of the customer's order. No one service level measure will be appropriate for all the items in the inventory. [Ref 20:p. 211]

A commonly used definition of service level is the fraction of demands that are immediately filled from stock. This is also called the fill rate. This measure is inversely related to the number of backorders.

The fill rate is calculated by using two global variables at each base. These are used to count the number of failures at that base and the associated number of backorders. Since every failure generates a demand for a spare, the number of demands is the same as the number of failures. At the end of each sample period, these variables are called into subroutine STATS and converted into a percentage of demands filled immediately and output in the summary report.

5. Operational Availability

Operational availability is "the probability that a system or equipment, when used under stated conditions in an actual operational environment, will operate satisfactorily when called upon" [Ref. 14:p. 65]. Operational availability is calculated as:

$$A_0 = \frac{\text{MTBM}}{\text{MTBM} + \text{MDT}} = \frac{\text{MTBM}}{\text{MTBM} + \text{MTTR} + \text{ADT} + \text{MSRT}}$$

where MTBM is the mean time between maintenance and MDT is the mean down time. MDT is composed of three elements: logistic delay time (LDT) or Mean Supply Response Time (MSRT), which is the time waiting for a spare due to logistics factors; administrative delay time (ADT); and the active maintenance time to repair the item when all spares and equipment are available (MTTR). A more detailed description of these factors is given at Reference 14, page 44. In the simulation model, ADT is assumed to be zero.

The operational availability in each sample period is obtained by interpreting a statistic calculated by SLAM II for queue nodes associated with service activities. SLAM II automatically collects many statistics that the programmer can access, one of which is the utilization of the servers connected to a queue node. For example, if there are nine identical servers connected to a queue and, on average they are busy 85% of the time, then SLAM II calculates that the average utilization is 7.65 servers (9x0.85). The value is in terms of servers (7.65) rather than the utilization ratio (0.85). MEEBS is structured in such a way that the average utilization of the servers directly relates to the operational availability of the RI at the base.

Normally, the function of a queue node is to store entities until a server is available. However, MEEBS is structured so that a spare is not released from a base store until a RI has failed and a replacement is demanded. Hence when an entity arrives at the queue node, there is always a server free representing the down system, and the entity immediately enters service. All these events occur in zero time. If the base store has no spares then the server remains idle until the store receives a spare. Therefore, the amount of time a server is idle represents the amount of time that the system is down awaiting a spare. This average of time is, in effect, the mean down time due to maintenance, administration and supply delays. Hence, dividing the average number of the servers utilized by the total number servers gives the operational availability of the RIs at that base. This conversion is done in subroutine STATS at the end of every sample period.

O. SUBROUTINES

There are six subroutines written in FORTRAN that complement the larger part of the program which is written using SLAM II commands. The names of the subroutines are: MAIN; INTLC; EVENT; CANBO; STATS; and, LATSUP.

MAIN is used to redimension the default parameters of SLAM II. The parameters that are redimensioned are NSET and QSET which limit the maximum number of entities that can concurrently exist in the program. This is explained in Reference 5, page 389.

Subroutine INTLC is used to initialize the variables used in the subroutines and to schedule the calculation of system statistics at the end of every sample period. The reader is referred to Reference 5, page 309 for further details.

Subroutine EVENT is used to define user written subroutines that are called by the part of the program written in SLAM II. This is discussed further in Chapter IV. The reader is also referred to Reference 5, page 292, for further details.

Subroutine CANBO cancels unnecessary backorders and is a function of the backorder procedure simulated. This is because the model simulates the backorder process by sending a demand to one or more stores in the system as discussed in the Section K: Demand and Backorder Rules. When a store responds to the backorder demand, the other demands must be cancelled. If the backorder rules in the model are changed so that only one backorder demand is injected into the system then CANBO would not be required. This latter system would model the military system where there is an item manager for the RI of interest and the manager confirms where the next serviceable RI will become available.

Subroutine LATSUP is called whenever a base requests lateral resupply. LATSUP first searches for the closest base, in terms of shipping time, that has a spare. This is achieved by using the SLAM II GETARY and NNQ commands in a FORTRAN IF statement. The GETARY command imports into LATSUP the lateral resupply times for the bases. The NNQ is used to determine the number of entities in the spares queue at each base. If two or more bases have spares the same LRT then the base with the most spares is selected. This is implemented using FORTRAN IF statements. Once a donor base has been determined, LATSUP inserts an entity representing a lateral resupply demand into the demand queue of the donor base using the SLAM II FILEM command. This entity is then processed the same way as other demands using the value of Attribute 2 to determine which base to ship to. LATSUP also inserts a demand entity into the ILM demand queue to send a replacement spare to the donor base when it has a spare available. If lateral resupply is not possible, LATSUP sets Attribute 6 equal to one. This is used as a flag by the network to indicate that lateral resupply was attempted but was unsuccessful.

Subroutine STATS is called at the end of every sample period to calculate system statistics for the period. The operation of this subroutine has been described earlier in the sections on performance measures.

IV. HOW TO USE THE MODEL AND SOME SAMPLE RESULTS

A. INPUT DATA

One of the objectives when designing the model was to make it easy to use. Therefore, the amount of input data required has been kept as small as possible and, with the exception of a few parameters, all data are input via SLAM II data arrays or global variables at the front of the program. The data to be input by the user are:

- the number of bases (from one to six) and the number of repair echelons (from one to three);
- the number of RIs operating at each base and their mean failure rate;
- the probability of repair at each maintenance echelon (the sum of the probabilities must equal 1.0);
- the number of repair stations at each maintenance echelon and their mean repair times;
- the number of spares and their distribution among the stores;
- the shipping times between bases and maintenance facilities; and,
- whether there is lateral resupply between bases.

B. HOW TO INPUT THE MODEL PARAMETERS

Input parameters that may be frequently changed are input at the start of the program using either initialization statements or SLAM II data arrays. Due to the way some SLAM II functions are defined, a few, less frequently changed parameters are input in the body of the program or, in the case of the sample time, in the subroutines.

Most of the terms used for parameters are formed from an abbreviation or acronym for the parameter followed by a combination of one or two letters or numbers. The letters I or ILM and D or DLM define ILM and DLM respectively, and a number defines a base. If there are two letters/numbers then, the first defines the origin of the activity and the second defines the destination. For example, NSYS1 is the number of operating systems at Base 1 and FST1D is the forward shipping time from Base 1 to depot level maintenance. All time parameters are dimensioned in days.

1. Initialize Statements

The *initialize* statements INTCL at the start of the network part of the program are used to define the values of SLAM II global variables that have an initial value other than zero. A global variable is a variable that maintains a value until changed by the user in the model and is written as XX(I) where I is the variable number. Normally constants are entered using data arrays as discussed in the following section but global variables are used for several constants in the model as some SLAM II functions will not accept other means of input. For example, the mean of the failure rate of the RIs at a base is a constant because the SLAM II density functions will not accept other forms of remote input.

The initialization block as used in the program is shown in Figure 4-1. The first ten lines are comment statements which define what each global variable is used for. The following seven lines are the actual initialization statements. The parameters are in the form of an acronym with either a number or letter on the end. The acronyms are: TMS (Time to Make Serviceable) which is the mean repair time; STD (Standard Deviation) of the repair time; and MTBF (Mean Time Between Failures).

```
;INITIALIZE GLOBAL VARIABLES
;-------------------------
;XX(27)=TMSD, XX(28)=STDD, XX(29)=TMSI, XX(30)=STDI
;XX(31)=TMS1, XX(32)=STD1, XX(33)=MTBF1
;XX(34)=TMS2, XX(35)=STD2, XX(36)=MTBF2
;XX(37)=TMS3, XX(38)=STD3, XX(39)=MTBF3
;XX(40)=TMS4, XX(41)=STD4, XX(42)=MTBF4
;XX(43)=TMS5, XX(44)=STD5, XX(45)=MTBF5
;XX(46)=TMS6, XX(47)=STD6, XX(48)=MTBF6
;------------------------------------------
INTCL,XX(27)=90, XX(28)=18, XX(29)=30,  XX(30)=6,
      XX(31)=10, XX(32)=3,  XX(33)=100,
      XX(34)=10, XX(35)=3,  XX(36)=180;
INTCL,XX(37)=10, XX(38)=3,  XX(39)=140,
      XX(40)=10, XX(41)=2,  XX(42)=100,
      XX(43)=10, XX(44)=2,  XX(45)=110,
      XX(46)=10, XX(47)=2,  XX(48)=110;
```

Figure 4-1. Initialization Statements for Global Variables

2. SLAM II Data Arrays

An array is a means of inputting parameters in a table format consisting of I rows and J columns. The SLAM II array statement is in the form of *ARRAY(I,J)/parameter values*. The model has an ARRAY statement for each base, ILM, DLM, and a system array. These are shown in Figures 4-2 to 4-5, respectively. The lines that begin with a semicolon are comments statements that define each parameter in the array.

```
;BASE 1 DATA. (1-7) NSYS1, LRT11,LRT12,LRT13,LRT14,LRT15,LRT16,
;-----------------------------------------------------------
;(8-10) P1DLM,P1ILM,P1OLM, (11-16) FST1I,RST1I,FST1D,RSTD1,AH1,AS1
;-------------------------------------------------------------
ARRAY(1,16)/12,0,1,1,1,1,1,0.4,0.3,0.3,2,2,4,4,3,3;
```

Figure 4-2. Parameter Array For Base 1

In the arrays for each base, the parameters input are:

- The number of systems in operation at the base (NSYS1);
- The lateral resupply times (LRT) between that base and each of the other bases. For example, LRT12 means the resupply is from Base 1 to Base 2.

- The probability of repair at each maintenance echelon for the RIs that fail. P1DLM indicates that the parameter is the probability of repair at DLM for a RI that fails at Base 1. P1ILM and P1OLM are the probabilities that a failure at Base 1 will be repaired at ILM or Base 1, respectively.
- The Forward Shipping Times (FST) from Base 1 to ILM and DLM.
- The Return Shipping Times (RST) from ILM and DLM to Base 1.
- The Authorized Holding (AH) level of spares and the Authorized number of Spares (AS).

AS1 is the number of spares that Base 1 should have. If the base does not have AS1 spares, then there is either an outstanding demand or backorder for every spare it is short. If the base receives spares in excess of AS1 then the excess are shipped to ILM. Any excess at ILM are shipped to DLM. AH1 is used by the program to remove bases or echelons from the model if the number of bases is less than six or the number of echelons is less than three. Normally, AS1 and AH1 are the same value unless the number of spares is zero in which case AS1 is set to zero and AH1 to one.

```
;ILM DATA. FSTID, RSTDI, AHI, ASI
;-------------------------------
ARRAY(8,4)/2,2,1,1;
```

Figure 4-3. Parameter Array For ILM

The array for ILM defines the forward shipping time to DLM, the return shipping time, the authorized holdings of spares (AHI) and the authorized spares at ILM (ASI). The function of ASI and AHI is the same as AS1 and AH1, respectively.

```
;DLM DATA. ASD
;------------
ARRAY(9,1)/1;
```

Figure 4-4. DLM Array

The DLM array defines the authorized spares holding (ASD) for the depot.

The system's options array defines switches or values that are used by the network and subroutines (see Figure 4-5). Fields 1 to 3 of the array define, respectively, the number of maintenance echelons, the number of bases, and whether lateral resupply is used. This ensures the correct flow of RIs. Fields 4 and 5 are used by subroutine STATS to calculate the long-run average of the performance measures after the model has reached steady state. Field 4 defines when the SLAM II statistical arrays are cleared. Field 5 states the end time for the simulation. The use of these fields is more fully discussed in the section on simulation run time and clearing of arrays.

```
;SELECT OPTIONS
    ;--------------
    ;FIELD1 = # MAINTENANCE LEVELS. 3=3 LEVELS, 2=2 LEVELS, 1=1 LEVEL
    ;      2 = # BASES (1...6)
    ;      3 = LATERAL RESUPPLY (= 1 SET, 0 = NOT SET).
    ;      4 = TIME WHEN SLAM II STAT ARRAYS ARE CLEARED
    ;      5 = END TIME FOR SIMULATION RUN
    ; NOTE: VALUES FOR FIELDS 4 & 5 MUST BE A MULTIPLE OF THE SAMPLE TIME
    ;
    ARRAY(10,5)/3,2,1,10000,20000;
```

Figure 4-5. Parameter Array For System Options

3. Other Input Parameters

Some SLAM II commands will not accept parameters input via arrays or global variables. Instead, the numerical value of the parameter or, in the case of probability density functions, the name of the distribution must be written in the command statement where it is used. Fortunately, the parameters affected are few and they are parameters that generally will not require frequent changing. The parameters affected and where they are input is discussed in the following subsections.

a. *The Number of Servers and Density Distributions*

Servers are used to model the operation of the RIs at each base and the maintenance resources at the maintenance facility. The probability density functions define the distribution of the activity being modeled. Maintenance activities at Base 1 are defined by the following SLAM II statements:

```
OLM1   QUEUE(21);                              AWAIT REPAIR
       ACT(5)/45,RLOGN(TMS1,STD1,3);           OLM1 REPAIR
```

There are six such pairs of statements, labeled from OLM1 to OLM6 for operating level maintenance at Bases 1 to 6, respectively. There are two other pairs of statements labeled ILM and DLM for the ILM and DLM activities, respectively. The number in brackets following ACT defines the number of servers at the maintenance echelon. In the above statement the number of servers is 5. The /45 is the activity number and this causes SLAM II to collect statistics based on the number and distribution of entities through the activity. RLOGN(TMS1,STD1,3) defines the probability density distribution for the maintenance activities to be lognormal with a mean of TMS1 and a standard deviation of STD1. The number 3 defines the random number stream that is used to generate the activity times based on the distribution data.

To change the number of servers, the user inputs the desired number of servers into the statement. To change the density function, the user changes the name using SLAM II abbreviations. Distributions available are: Erlang (ERLNG); Gamma (GAMMA); Poisson (NPSSN); lognormal (RLOGN); triangular (TRIAG); uniform (UNFRM); Weibull (WEIBL); or any custom distribution input by the user. The reader should refer to Reference 5, page 108, for further details of the distributions and their syntax. The mean and standard deviation are changed using array statements as previously discussed.

The operation of the RIs at a Base 1 is simulated by the following SLAM II statements:

```
SYS1    QUEUE(31);
        ACT(30)/1,EXPON(MTBF1,2);              OP SYS U1
```

There are six such pairs of statements in the model, one for each base. The statements are labeled SYS1 to SYS6 for Bases 1 to 6 respectively. The number 30 in brackets following ACT defines the number of servers to be 30. The /1 is an activity number. Whenever an activity number is specified, SLAM II collects statistics on the entities that flow through the activity. Normally, the value of the number is not significant, but in the case of the SYS activities, the activity numbers are used in the subroutines and must not be changed by the user. EXPON(MTBF1,2) defines the distribution to be an exponential distribution with a mean of MTBF1. The number 2 defines the random number stream that is used to generate activity times from the distribution.

Due to the way the program is written, the number of servers representing the RIs only has to be equal to or greater than the number of operating systems at the base. The actual number of systems simulated by the model is set by the parameter NSYS1 previously discussed. Hence, to minimize the number of times that the number of servers must be changed, the user should set the number of servers equal to the maximum number of systems likely to be simulated.

b. Simulation Run Time and Clearing Statistical Arrays

The run time for the simulation and the time at which the SLAM II statistical arrays are cleared or reset are input by the user at the end of the network program using the following SLAM II statements:

```
INIT,0,20000;
MONTR,CLEAR,10000.001;
```

The INIT statement defines the start of the simulation run as time zero and the run length as 20,000 days. The run length can be any time desired by the user. From runs to date, 20,000 days appears to give reasonable results without incurring excessively long execution times.

At time zero, all RIs in the model are serviceable and all the maintenance facilities are idle. For the simulation to reach a steady state which represents the mature operation of the logistics system, five to ten thousand simulation days are required to remove cyclic trends from the statistical results. SLAM II automatically collects statistics from time zero. To remove the statistics for the period prior to steady state, the MONTR statement is used to reinitialize the arrays that SLAM II uses to store statistics. For the statistics calculated by SLAM II and the subroutine STATS to relate to each other, the run and CLEAR times must be a multiple of the sample time input by the user in subroutine STATS. The .001 is added to the CLEAR value to prevent a timing problem with subroutine STATS. The actual value is arbitrary and only needs to be a small fraction. If it is not added to the

CLEAR time then the system statistics for the sample period ending at time CLEAR will be zero because SLAM II clears all of the statistical arrays before subroutine STATS can calculate the statistics for that period. The values for the CLEAR and run times should not need to be changed once suitable values have been found. Values of 10,000 and 20,000 are recommended as initial values for CLEAR and run time, respectively. The reader is also referred to comments in the next section on sample time.

c. Sample Time and Run Time For Statistics

In performing statistical analysis, a method is needed for generating independent samples of the performance measures. This drives the choice of the sample time, SAMPLT. Suppose the measure of interest is operational availability (A_O) and we run the simulation for 1,000 days with SAMPLT equal to 10 days. This would give 100 samples of A_O. However, these samples are not independent. This can be seen if we assume that one of the samples produced a result of 0.0 for A_O which means that no systems were operational during the ten day sample period. Due to the length of the repair times and limited maintenance resources, the value of A_O will also be close to zero in the next sample period as it is influenced by events in the preceding period. This inter-period influence can be minimized by increasing the value of SAMPLT.

If we now consider a SAMPLT with a value of 500 days, the sample values for A_O obtained in each sample period should be nearly independent as the sample time is large compared to the events being simulated. However, only two samples would be produced in a run of 1,000 days. Hence there is a trade-off between nearly independent samples which is a function of SAMPLT and the size of the sample which is a function of SAMPLT and run time. Therefore, a value for SAMPLT should be chosen so that the resulting samples pass a statistical test for independence such as the Chi-Squared test, while keeping SAMPLT as small as possible to maximize the number of samples and keep the simulation run time reasonable.

SAMPLT is used by subroutine STATS to calculate several performance measures based on a sample period determined by the user. The sample time appears twice in the subroutines, once in subroutine INTLC and once in STATS. The FORTRAN statement used in both cases is "PARAMETER (SAMPLT = 500.0)" where 500.0 is the sample time (in days). Real-life data was unavailable and therefore statistical tests like the Chi-Squared test were not used to select the values of SAMPLT used to generate the results discussed in this thesis. Rather, the choice of SAMPLT was based on observation of the results. Sample times between 500 to 1,000 days have been found to give fairly stable results. However, due to the fact that the values for the performance measures oscillate about a mean once the system is in steady state, the longer the sample period, the more the average of the measured values converge towards these mean values and the less is the variation between results for different periods. The user should experiment with the times to find a suitable time but an initial value of 500 is recommended.

Run times in the range of 15,000 to 20,000 days were used as the model requires 7,000 to 10,000 days to reach steady state before valid data can be collected. This is discussed in detail in the section on steady state.

B. CONFIGURING THE MODEL

If the model is run using six bases and three maintenance echelons, then it is fully configured through the input of the model parameters as described above. If the model is operated with less than six bases, the active bases must be consecutive starting with Base 1 through to the desired number of bases. For example, if the desired configuration is three bases then they must be numbered from one to three. Also, the following parameters must be set to zero for each base that is not used: AH, AS, and NSYS.

If the model is configured for only two maintenance echelons, the model assumes there is only OLM and ILM. The part of the model defined as DLM is made inactive by setting Array(10,1) to 2 (for two echelons) and field 8 of the arrays for the bases to 0. The sum of the maintenance probabilities in fields 8 to 10 of the base arrays must equal one. Note, the ILM parameters for the number of spares, and the number of servers and service time can be amended to reflect DLM values (i.e., so the model reflects a two-echelon system consisting of bases and a depot).

If the model is to reflect only one maintenance echelon, the model assumes that the only maintenance level is OLM at each of the bases. ILM and DLM are made inactive by setting: Array(10,1) to 1 (for one echelon), and fields 8 to 10 of the arrays for each active base to 0, 0, 1, respectively. This will send all failed RIs at a base to that base's OLM facility.

C. SAMPLE RESULTS FROM THE MODEL

The examples discussed in this section are intended to explain how to interpret the data provided by the model and to illustrate how the data can be used to provide insight into the performance of the logistics system being modeled. Also, some brief examples of how the data can be used for sensitivity analysis are given.

It is important to note that before any valid conclusions can be drawn, several simulation runs would need to be done using the same configuration but different seed values for variables whose values are drawn from the probability density functions in the model. The results of the model should change a little every time the seed values are change. The mean values of the runs should provide a reasonable estimate of the parameters of interest.

The model provides three groups of statistics. The first two groups are various performance measures calculated by subroutine STATS. The third group are general system statistics collected by SLAM II within the network section of the model.

1. Model Statistics and Steady State

At the start of the simulation run all RIs in the system are serviceable and all maintenance facilities are idle. Hence it takes an initial period for the failures to occur and for the demand for spares and maintenance resources to reach levels typical of long term or mature operation. Generally, it is the performance of the logistics system when in steady state that is of interest. While the model can be used to evaluate the effect of introducing a new system into service, the examples discussed in this chapter relate to when the logistics system is in steady state.

The effect of start-up time is shown in Figure 4-6 which plots operational availability against time for three bases with different failure rates but the same number of spares, and the same maintenance times and capacities. Lateral resupply did not occur. From the graph it can be seen that the system being modeled did not reach a steady state until 7,000 to 8,000 days of operation. This is typical of most runs done to date and therefore, 10,000 days is recommended as the default value for time CLEAR.

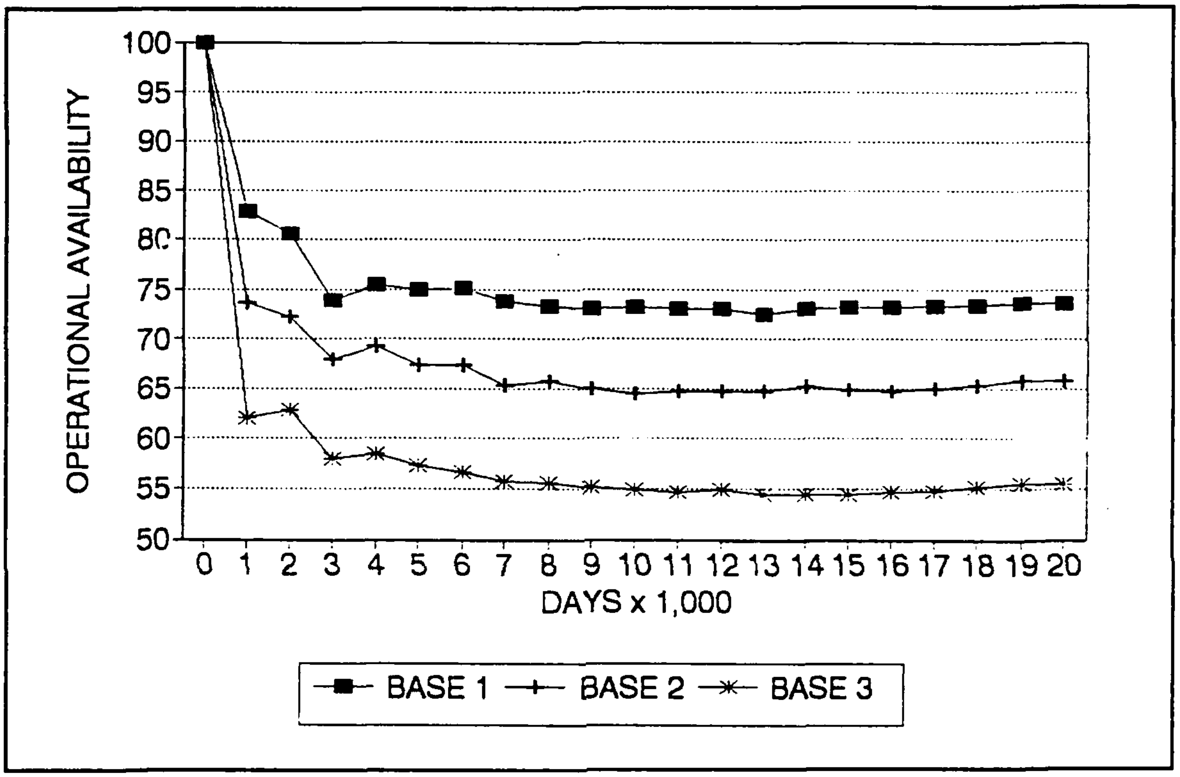


Figure 4-6. Model Start-Up Effects on Operational Availability (three bases with 12 systems at each base but different failure rates, and no lateral resupply)

2. Performance Measures

The statistics calculated by STATS are based on data collected by the model over a sample period specified by the user. The sample period can be any time period but, in simulation runs to date, sample periods between 500 to 1,000 days have resulted in fairly stable results from one sample period to the next except during the first 7,000 to 10,000 days when the system is settling down to a steady state. As discussed earlier, the number of sample periods is limited by the length of the simulation run.

The first group of performance measures calculated by STATS is provided at the end of each sample period and is based on the data collected during that period. The results are output to a summary report which is available at the end of the run. The format of the summary report in shown in Figure 4-7. The statistics (and column headings) are: service level (SL %); the number of backorders per 100 days; the average duration days of the backorders; the time weighted backorders per day; the mean supply response time; and the operational availability and its standard deviation. The results from each sample period can be plotted for a single parameter to produce a graph like Figure 4-6 that compares the performance of various bases or several parameters can be plotted as in Figures 4-8 and 4-9 to evaluate the effectiveness of the parameters themselves. (Note: The graph shows TWBO/15 days so that the relationship between TWBO and the other performance measures is easier to see.) The data plotted in Figures 4-8 and 4-9 are for the same base and are from a single simulation run.

SYSTEM STATISTICS FOR SAMPLE PERIOD ENDING AT TIME 12000.00

BASE	SL%	B ORDERS /100 DAYS	AVG BO TIME IN DAYS	TWBO BO-DAYS/DAY	MSRT IN DAYS	OPERATIONAL AVAIL%	STD DEV%
1	18.2	0.108E+02	0.134E+02	0.145E+01	0.110E+02	89.1	11.4
2	98.1	0.200E+00	0.479E+01	0.959E-02	0.922E-01	100.0	0.4

Figure 4-7. Performance Measures Report for a Two Base Simulation. (The sample period was 1,000 days and the period ended at time equal 12,000 days)

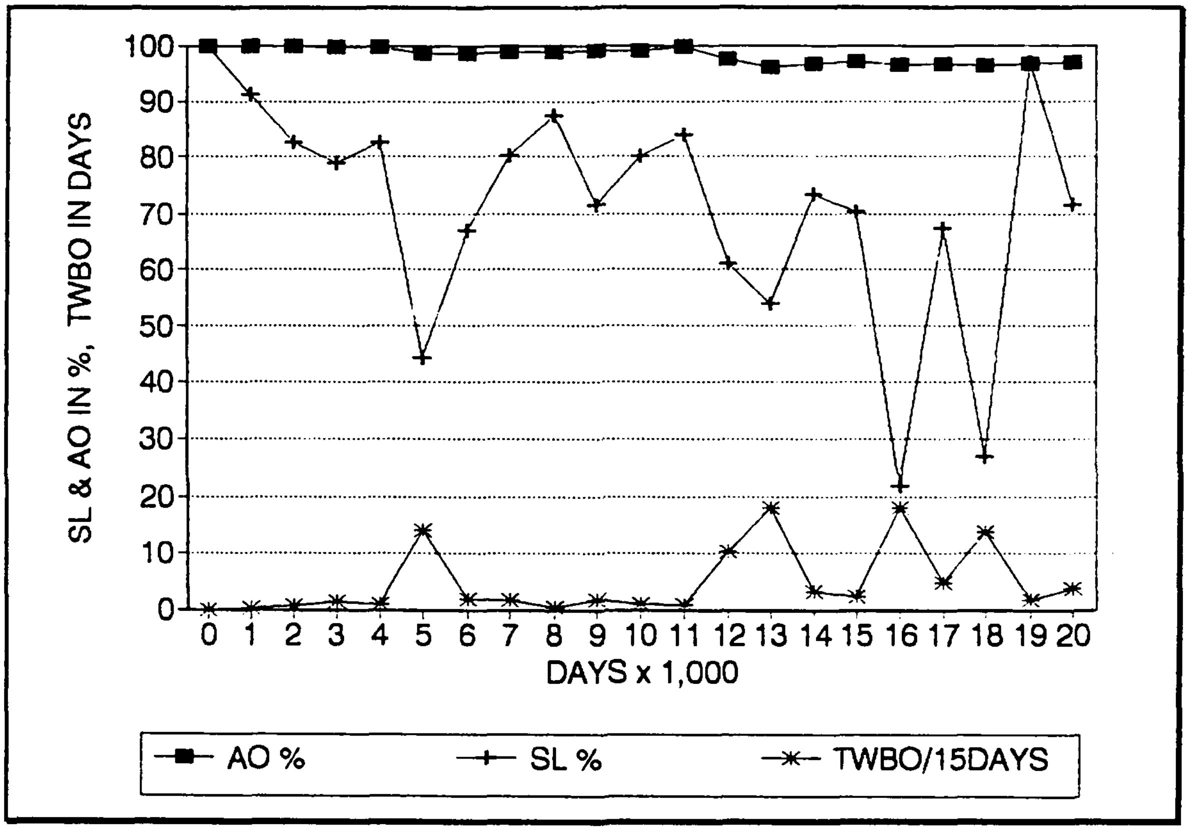


Figure 4-8. Plot of Service Level (SL), Operational Availability (AO), and Time Weighted Backorders per 15 days (TWBO/15DAYS) for Base 1

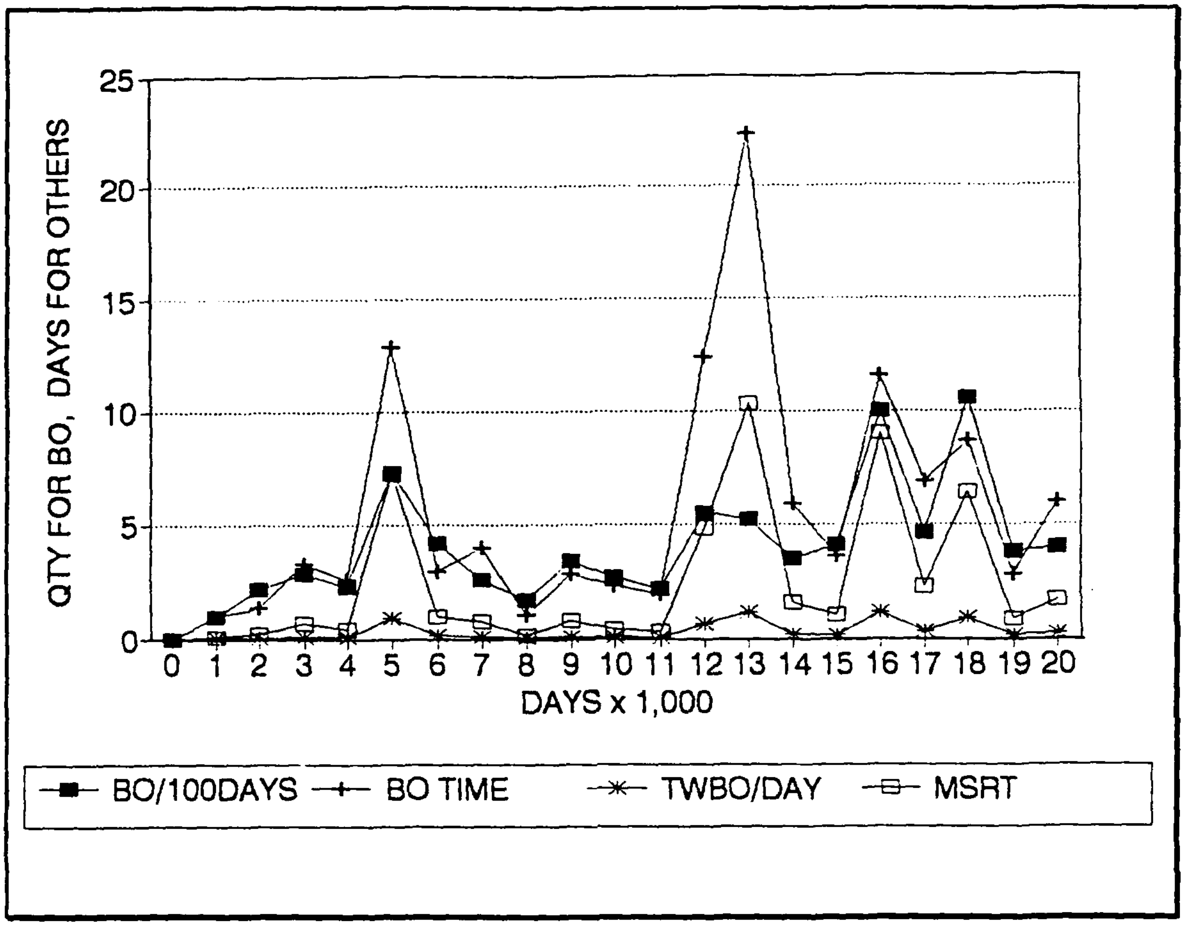


Figure 4-9. Plot of the Number of Backorders (BO) per 100 days, the Average Backorder Duration in Days (BO TIME), Time-Weighted Backorders in Backorder-Days per Day (TWBO), and Mean Supply Response Time (MSRT)

The second group of statistics from subroutine STATS are the same performance measures but calculated using the data collected from the time the statistical arrays are reinitialized by the CLEAR statement to the end of the simulation run. In effect the sample period for this group is in the order of five to ten thousand days and therefore they provide an accurate and stable measure of the parameter. These values provide an easy means of comparing the results of various bases and configurations from different simulation runs. These statistics are also output in the summary report in the format shown in Figure 4-10.

```
SYSTEM STATS FROM TIME CLEAR TO END. SAMPLE PERIOD (DAYS) = 10000.00

BASE  SL%    B ORDERS  AVG BO TIME   TWBO        MSRT          OPERATIONAL
             /100 DAYS IN DAYS      BO-DAYS/DAY IN DAYS        AVAIL%

  1  16.7  0.112E+02  0.158E+02   0.160E+01  0.132E+02       89.3
  2  99.7  0.300E-01  0.443E+01   0.121E-02  0.146E-01      100.0
```

Figure 4-10. Performance Parameters Based on a Long Sample Time of 10,000 Days

3. Other Statistics

The third group is statistics collected by SLAM II based on the configuration of the network. These include such data as the total number of failures and backorders at each base and the number of lateral resupplies which occurred between bases. The program can also produce histograms for selected statistics in this group. However, for these statistics to be valid in terms of measuring the steady state or mature performance of the logistics system, the statistical arrays associated with these statistics must be reinitialized once the model is in steady state. This is achieved using the MONTR, CLEAR, statement as previously discussed.

To explain the statistics that are available, the results for Base 1 from a three-echelon, six-base simulation run are discussed. The configuration of the system is shown in Figure 4 - 11. An edited version of the full summary report showing the statistics that are available for Base 1 is at Figure 4-12. (A copy of the full summary report for the data discussed in this section is included at Appendix D). Similar data is available for all bases. The statistics are based on data collected over the period from time CLEAR to the simulation end time. These times are printed at the top of the report and are 10,000 days and 20,000 days, respectively.

```
                    COMMENTS ON SIMULATION
                    **********************

DATE: 13 JUNE 90
TIME: 1220

NUMBER OF BASES: 6
LATERAL RESUPPLY: YES
NUMBER OF MAINTENANCE LEVELS: 3
RUN TIME: 20,000 DAYS
SAMPLE TIME: 1,000 DAYS
                                           MAINTENANCE   DATA
                                  -------------------------------------
BASE SPARES #SYSTEMS MTBF #SERVERS TMS STD  P(DLM) P(ILM) P(OLM)
---- ------ -------- ---- -------- --- ---  ------ ------ ------
DLM     3                     14     90  14
ILM     4                      9     30   6
  1    10      16     200      5     10   3    .4     .3     .3
  2    10      16     220      5     10   3    .4     .3     .3
  3    10      16     400      5     10   3    .4     .3     .3
  4    10      16     140      5     10   3    .4     .3     .3
  5    10      16     280      5     10   3    .4     .3     .3
  6    10      16     270      5     10   3    .4     .3     .3

SHIPPING TIMES
--------------

        ILM      DLM                LRT
----  -------  -------  -----------------------
BASE  FST RST  FST RST   1   2   3   4   5   6
----  --- ---  --- ---  --- --- --- --- --- ---

  1    2   2    4   4    -   1   1   1   1   1
  2    2   2    4   4    1   -   1   1   1   1
  3    2   2    4   4    1   1   -   1   1   1
  4    2   2    4   4    1   1   1   -   1   1
  5    2   2    4   4    1   1   1   1   -   1
  6    2   2    4   4    1   1   1   1   1   -

ILM    -   -    4   4
DLM    2   2    -   -
```

Figure 4-11. Configuration of the Three-Echelon, Six-Base Simulation Run

CURRENT TIME 0.2000E+05
STATISTICAL ARRAYS CLEARED AT TIME 0.1000E+05

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TMS DIM	0.4266E+03	0.4645E+02	0.1089E+00	0.2778E+03	0.5666E+03	1553
TMS IIM	0.3029E+02	0.5802E+01	0.1916E+00	0.1554E+02	0.5570E+02	1225
AVG OP TIME B1	0.1987E+03	0.1909E+03	0.9611E+00	0.2585E+00	0.1106E+04	740
SYS1 DOWN TIME	0.1779E+02	0.1676E+02	0.9423E+00	0.0000E+00	0.6907E+02	744
TMS BASE1	0.9753E+01	0.2986E+01	0.3062E+00	0.3874E+01	0.2283E+02	228

FILE STATISTICS

FILE NUMBER	LABEL/TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	DU1 QUEUE	1.3074	1.4154	8	2	15.4716
8	DI QUEUE	16.7596	12.1906	69	14	48.3542
9	SI QUEUE	0.0010	0.0380	2	0	0.0084
10	IIMQ QUEUE	0.0025	0.0501	1	0	0.0206
11	SU1 QUEUE	0.1346	0.5289	6	0	1.5970
21	OMQ1 QUEUE	0.0000	0.0000	0	0	0.0000
28	DD QUEUE	6.0762	5.2182	21	14	19.6830
29	SD QUEUE	0.1031	0.4389	5	0	0.6642
30	DIMQ QUEUE	52.3349	6.8052	68	60	324.4566

REGULAR ACTIVITY STATISTICS

ACTIVITY INDEX/LABEL	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL	ENTITY COUNT
7 # SD TO IIM	0.0002	0.0141	1	0	1
8 # DIM - U1	0.1110	0.3340	3	0	278
15 RESUP I FM D	0.0000	0.0000	1	0	4
16 # IIM - U1	0.0432	0.2078	2	0	216
23 EX SI TO DIM	0.0000	0.0000	0	0	0
24 DIM REPAIR 1	0.0000	0.0000	1	0	300
25 IIM REPAIR 1	0.0000	0.0000	1	0	212
26 OIM REPAIR 1	0.0000	0.0000	1	0	228
27 #BO BASE 1	0.0000	0.0000	1	0	679
28 U1-TRY LRS	0.0000	0.0000	1	0	641
30 LRS1-2	0.0019	0.0435	1	0	19
31 LRS1-3	0.0016	0.0400	2	0	16
32 LRS1-4	0.0034	0.0592	2	0	34
33 LRS1-5	0.0008	0.0283	1	0	8
34 LRS1-6	0.0022	0.0469	1	0	22
36 EX S1 TO IIM	0.0000	0.0000	0	0	0
42 # LRS2-1	0.0025	0.0499	1	0	25
55 # LRS3-1	0.0042	0.0647	1	0	42
68 # LRS4-1	0.0019	0.0435	1	0	19
81 # LRS5-1	0.0012	0.0346	1	0	12
91 # LRS6-1	0.0023	0.0479	1	0	23

SERVICE ACTIVITY STATISTICS

ACTIVITY INDEX	START NODE OR ACTIVITY LABEL	SERVER CAPACITY	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM IDLE TIME/SERVERS	MAXIMUM BUSY TIME/SERVERS	ENTITY COUNT
1	OP SYS U1	20	14.6926	1.4154	12.0000	16.0000	740
14	DIM REPAIR	14	14.0000	0.0000	0.0000	14.0000	1553
22	IIM REPAIR	9	3.7069	1.8588	9.0000	9.0000	1225
35	OIM1 REPAIR	5	0.2224	0.4688	5.0000	3.0000	228

Figure 4-12. SLAM II Network Statistics for Base 1 in a Six-Base, Three Echelon Simulation with Lateral Resupply

The first block of statistics are statistics collected for the maintenance activities and system operation. These statistics are based on the observation of the attributes (characteristics) of the entities (RIs) as they pass through SLAM II collect (COLCT) nodes in the network.

The maintenance statistics are the time to make serviceable (TMS) at the depot (DLM), intermediate (ILM), and operational (OLM) level facilities. The statistics computed are the actual simulated mean repair time which includes the time a RI spends waiting in the maintenance queue for a server, the standard deviation of the simulated repair time, and minimum and maximum values. The number of entities (RIs) that have passed through each activity is also given in the column headed "Number Of Observations". For example, for DLM, there were 1553 RIs repaired with a mean repair time of 426.6 days and a standard deviation of 46.45 days. The quickest repair was done in 277.8 days and the longest took 566.6 days. This is very long considering the input value of the mean TMS time was 90 days. (Note: there is always some variation between the value input by the user and the actual result as the actual repair time is a random variable selected by a pseudo-random number stream from a probability density function). The difference between the mean repair time calculated by the simulation and the value of TMS input is the time the RIs spent in the queue waiting for a server. This is confirmed by the File Statistics for the DLM queue (DLMQ) which show that the average waiting time was 324.5 days and the average number of RIs waiting was 52.3 with a maximum of 68. Also, the Service Activity Statistics for DLM repair at the bottom of Figure 4-12 show that there were 14 servers available and all were fully utilized during the 10,000 day observation period.

Hence the long waiting time. The "Entity Count" is identical to the "Number Of Observations" and indicates the number of RIs that went through the DLM activity.

The maintenance statistics for ILM indicate an actual mean repair time of 30.29 days. The TMS input by the author was 30 days. The Service Activity Statistics for ILM indicate that there were nine servers with a mean utilization of 3.7 servers. The File Statistics for ILMQ show that on average, the number of RIs waiting for maintenance was 0.0025 and the average waiting time was only 0.02 days. At some time during the 10,000 days observation period, all servers were idle (see the column under the heading of Maximum Idle Time/Servers) and at some other time, all servers were busy (Maximum Busy Time/Servers column). Similar data is provided for OLM in the last row of data for Service Activity Statistics.

Further information on repair time can be obtained by requesting a histogram of the data. The histogram produced by SLAM II for ILM is shown at Figure 4-13. (Note, the histogram is rotated by 90° from the conventional format.) The data is summarized in four columns on the left hand side of the histogram. The column headed UPPER CELL LIMIT lists the scale of the vertical axis. The column OBSV FREQ gives the number of RIs that had a repair time that corresponds to the scale increment in the same row. Columns REL FREQ and CUML FREQ show the relative frequency and cumulative frequency, respectively. On the histogram, the relative frequency is indicated by the asterisks and the cumulative frequency by the "C". A data summary, which is the same as the Statistics Based On Observation data discussed above, is provided at the bottom of the histogram. The histogram clearly shows that the repair distribution is lognormal.

```
                                         TMS ILM

OBSV   RELA    CUML    UPPER
FREQ   FREQ    FREQ    CELL LIMIT   0         20        40        60        80        100
                                    +    +    +    +    +    +    +    +    +    +    +
   0   0.000   0.000   0.0000E+00   +                                                 +
   0   0.000   0.000   0.3000E+01   +                                                 +
   0   0.000   0.000   0.6000E+01   +                                                 +
   0   0.000   0.000   0.9000E+01   +                                                 +
   0   0.000   0.000   0.1200E+02   +                                                 +
   0   0.000   0.000   0.1500E+02   +                                                 +
   9   0.007   0.007   0.1800E+02   +                                                 +
  35   0.029   0.036   0.2100E+02   +*C                                               +
 114   0.093   0.129   0.2400E+02   +*****C                                           +
 201   0.164   0.293   0.2700E+02   +********      C                                  +
 268   0.219   0.512   0.3000E+02   +***********              C                       +
 242   0.198   0.709   0.3300E+02   +**********                        C              +
 168   0.137   0.847   0.3600E+02   +*******                                  C       +
  99   0.081   0.927   0.3900E+02   +****                                         C   +
  49   0.040   0.967   0.4200E+02   +**                                             C +
  21   0.017   0.984   0.4500E+02   +*                                               C+
  10   0.008   0.993   0.4800E+02   +                                                 C
   4   0.003   0.996   0.5100E+02   +                                                 C
   2   0.002   0.998   0.5400E+02   +                                                 C
   3   0.002   1.000   0.5700E+02   +                                                 C
   0   0.000   1.000   0.6000E+02   +                                                 C
   0   0.000   1.000   0.6300E+02   +                                                 C
   0   0.000   1.000   0.6600E+02   +                                                 C
   0   0.000   1.000   0.6900E+02   +                                                 C
   0   0.000   1.000   0.7200E+02   +                                                 C
   0   0.000   1.000   0.7500E+02   +                                                 C
   0   0.000   1.000      INF       +                                                 C
 ---                                +    +    +    +    +    +    +    +    +    +    +
1225                                0         20        40        60        80        100
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TMS ILM	0.3029E+02	0.5802E+01	0.1916E+00	0.1554E+02	0.5570E+02	1225

Figure 4-13. SLAM II Histogram for the Repair Times for the RIs at ILM

Returning to Figure 4-12, the operating statistics provided are the average operating time of the systems at Base 1 (AVG OP TIME B1) and the average down time of each system at the base (SYS1 DOWN TIME). The operating times of the systems at the bases are random variables draw from an exponential distribution based on a mean value input by the user. The mean achieved during the simulation was 198.7 days compared to an input value of 200 days. The shortest time a RI operated for was 0.258 days and the longest was 1,106 days.

Additional information on the operation of the systems can be obtained from the Service Activity Statistics at the bottom of Figure 4-12 from the first row of data labeled OP SYS U1. The server capacity of 20 indicates that the maximum number of operating systems that can be set by the NSYS1 input parameter without amending the program is 20. The section in Chapter III on the simulation of operating systems explains the rationale of this. In terms of interpreting the statistics, it is used as a reference point. For example, subtracting the maximum idle time/servers, 12, from the number of servers, 20, gives a result of eight which indicates that the minimum number of systems operating during the observation period was eight. The maximum busy time/servers indicates that at some point in time there were 16 systems operational. In this example, the number of operating systems at the base was 16 (refer Figure 4-11). The average number of systems operational over the period was 14.69.

The average down time, SYS1 DOWN TIME, is the total time it took to replace all failed RIs divided by the total number of failures. This time is actually the MSRT because the model assumes the time to replace a failed RI is zero once a spare is available. The average down time of the RIs at Base 1 was 17.79 days with the shortest time being zero days and the longest time being 69 days.

The File Statistics provides information on how much time the RIs spend in the various queues in the model. The file number is used for reference in the program and is of no interest to the user. The queues of interest relate to maintenance, demands and spares. The three queues that relate to maintenance are labeled DLMQ, ILMQ, and OMQ1 (Operating Maintenance Queue Base 1). The data for these queues was previously discussed. The queues that are labeled DU1, DI, and DD, are the queues for the demands for spares at Base 1, ILM, and DLM, respectively. (Note, U is used in many variables to signify a base because the original notation used in the model was Unit rather than Base but this was found to be confusing to people unfamiliar with the program). Looking at the demand data for DLM (labeled DD QUEUE), the average number of demands waiting at the depot store was 6.1 and they waited, on average, 19.7 days to be filled. The other data is self explanatory.

The queues that are labeled SU1, SI, and SD, are the queues associated with the spares in the stores at Base 1, ILM, and DLM, respectively. The data indicates that on the average the number of spare in stock was 0.135, 0.001, and 0.103, respectively. The maximum number of spares are also indicated under the heading "maximum length".

The only data of interest in the section labeled Regular Activity Statistics is the column headed Entity Count which provides data on the flow of RIs through the logistics system. # SD TO ILM indicates the number of RIs sent from the depot store to the ILM store which, in this case, was one. # DLM - U1 indicates the number of spares sent from the depot to Base 1, which was 278. RESUP I FM D indicates the number of times a replacement spare for ILM was requested from DLM. # ILM-U1 indicates the number of spares sent from the ILM store to the Base 1 store. EX SI TO DLM indicated the number of spares that were surplus to the ILM store's entitlement that were sent to the DLM store.

EX S1 TO ILM indicates the number of spares that were excess to Base 1's entitlement that were sent to the ILM store. In this simulation run the value is zero which means the maximum number of spares in the Base 1 store never exceeded the base's authorized limit which was ten. This fact can also be confirmed by looking at the File Statistics for SU1 QUEUE which shows that the maximum number (column headed Maximum Length) of spares was six.

The activities labeled DLM REPAIR 1, ILM REPAIR 1, and OLM REPAIR 1, indicate for the RIs that failed at Base 1, the number that were sent to DLM, ILM, and OLM Base 1, respectively. The sum of the three values is the total number of failures at Base 1 and dividing any of the values by this sum gives the proportion of failures sent to each echelon. This provides a check that the model is allocating the failures in accordance with the probabilities input by the user.

BO BASE 1 is the number of backorders at Base 1. U1-TRY LRS indicates the number of times lateral resupply was attempted to satisfy a backorder. The next six activities labeled LRS1-2 through to LRS1-6 indicate the number of times Base 1 provided spares in response to lateral resupply requests from other bases where the second number indicates the base requesting the spare. The second group of LRS statistics labeled # LRS2-1 to # LRS6-1, indicate the number of times Base 1 was successful in obtaining lateral resupply. The first number indicates the base supplying the spare.

4. Lateral Resupply

One of the interesting features of MEEBS is the ability to examine the effects of lateral resupply. The example discussed in this section is the same three-echelon, six-base system discussed above. The complete printout for the simulation run using lateral resupply is contained in Appendix D.

The statistics are based on the 10,000-day period from the time the statistical arrays were reset to the end of the simulation run. It is important to note that the configuration shown in Figure 4-11 is the configuration of the system at time zero. The statistical arrays were then cleared after 10,000 simulation days to remove the start-up bias that has been previously discussed. Hence the spares distribution within the system will be different at the start of the sample period of interest. From the data shown in the section labeled Service Activity Statistics in Figure 4-12, it is evident that on average, the number of RIs in maintenance at OLM Base 1, ILM and DLM was 17.92. This value is obtained by adding up the Average Utilization column for the maintenance facilities. Hence the number of spares available will be reduced by this amount. (Note, there was also RIs in OLM at the other bases). Also, since the model uses a (s-1,s) inventory policy, whenever a base issues a spare, it demands a replacement from the ILM store which in turn demands from the DLM store. Therefore, when there is a relatively high failure rate at several bases and a large number of RIs are tied up in maintenance, as in this example, the DLM and ILM stores are "bled dry" by the bases and even the bases hold significantly less than their authorized number of spares. This is indicated by the File Statistics in Figure 4-12 where the average number of spares at DLM (SD QUEUE) and at ILM (SI QUEUE) over the 10,000-day sample period were 0.0103 and 0.0010, respectively.

As previously discussed, whenever a base has a backorder, it first tries to obtain a spare from the ILM or DLM store. If it is unsuccessful, the base then tries lateral resupply. From the data presented in figure 4-12 in the section titled Regular Activity Statistics, it can be seen that Base 1 had 679 backorders (#BO BASE 1) and requested lateral resupply 641 times (U1-TRY LRS). Hence Base 1 was successful in obtaining a spare from the ILM or DLM store on only 38 occasions. From the data labeled # LRS2-1 to # LRS6-1 in the same section, it is evident that lateral resupply was successful 121 times or 18.88% of the time. It is also evident from the LRS data that Base 1 supplied 99 spares to other bases in response to requests for LRS. The configuration data in Figure 4-11 shows that the lateral resupply time (LRT) between any base was one day. Therefore, spares spent 121 days in transit from other bases to Base 1 and 99 days in transit from Base 1 to other bases for a total of 220 days and this was using a very short shipping time of one day. This is the major shortcoming of LRS, particularly in an environment where there are a large percentage of backorders.

Figures 4-14 and 4-15 show the performance measures obtained for this simulation with and without lateral resupply, respectively. As shown in Figure 4-11, all bases had the same number of spares and maintenance capacity. The only difference was the mean time between failure (MTBF) for the RIs operating at each base.

While all of the performance measures are related, the one that gives the best overall picture of how the support system of spares and maintenance facilities affect the operation of the RIs at the bases is operational availability (A_O). Comparing the operational availability (A_O) for the bases when lateral resupply was not used (Figure 4-15), it can be clearly seen that there is a large difference between the bases with Base 4 having an A_O of 80.9% and Bases 3, 5 and 6 having an availability of 100%. When these values are compared to the values of A_O achieved when lateral resupply was used, the bases that had 100% availability dropped to values that ranged from 92.0% to 95.4% while Base 4 improved from 80.9% to 88.0%. Hence in this case, lateral resupply had a dramatic leveling effect by giving the bases with higher failure rates access to the spares of other bases.

BASE	SL%	B ORDERS /100 DAYS	AVG BO TIME IN DAYS	TWBO BO-DAYS/DAY	MSRT IN DAYS	OPERATIONAL AVAIL%
1	7.5	7.48	20.0	1.36	18.5	91.0
2	9.9	6.63	19.8	1.19	17.8	92.0
3	10.9	3.76	19.3	0.658	17.2	95.4
4	12.8	9.55	21.1	1.83	18.4	88.0
5	9.7	5.42	21.6	1.07	19.5	93.3
6	11.0	5.73	22.7	1.18	20.2	92.0

Figure 4-14. System Statistics for the Three Echelon, Six Base Simulation with Lateral Resupply

BASE	SL%	B ORDERS /100 DAYS	AVG BO TIME IN DAYS	TWBO BO-DAYS/DAY	MSRT IN DAYS	OPERATIONAL AVAIL%
1	31.6	5.48	29.6	1.48	20.3	89.5
2	15.9	6.01	31.6	1.73	26.6	87.1
3	100.0	0.0	0.0	0.0	0.0	100.0
4	15.0	8.81	31.6	2.53	26.9	80.9
5	100.0	0.0	0.0	0.0	0.0	100.0
6	100.0	0.0	0.0	0.0	0.0	100.0

Figure 4-15. System Statistics for the Three-Echelon, Six-Base Simulation without Lateral Resupply

However, the overall performance of the system is worse with lateral resupply than without. For example, the overall A_O for the system decreased from 92.9% without LRS to 91.9% with LRS. Similarly, the average service level (as measured in terms of fill rate) decreased from 60.4% to 10.3% when LRS was used. This decrease in overall performance can be partly explained by the amount of time spares spent in transit between bases as previously discussed.

While caution should be used in drawing too many conclusions from one comparison, it is evident that lateral resupply is not always as beneficial as one might think.

5. Sensitivity Analysis

a. Varying the Number of Spares

The model can be used to evaluate the effect of changing the number of spares while keeping all other variables constant to determine the marginal gain or loss in performance from increasing or decreasing the number of spares. For ease of illustration, the model was configured as a three-echelon, single-base system with all spares allocated to the base. The MTBF was 200 days, the number of operating RIs was 16, and the mean repair times were 10 days, 30 days, and 90 days for OLM, ILM, and DLM, respectively. The number of servers at each echelon were such that the waiting time for a server was zero. The model was run with the number of spares at the base varying from zero to 11. The results of the runs are plotted in Figure 4-16.

When there were zero spares provided, the base had an A_O of 77%. This was purely a function of failure rate, and maintenance capacity and repair times. If the number of maintenance servers were reduced or the failure rate increased, then A_O would decrease. With zero spares, the service level is also zero as every demand is a backorder as there are no spares in the system. Hence a down system must wait until the failed RI is repaired before it can again become operational. Note that the average duration of a backorder (AV BO TIME) and the mean supply response time (MSRT) are the same. This is because every demand is a backorder.

As the number of spares increases, the performance measures that are availability related (A_O and service level) increase and the time/backorder dependent measures decrease.

The analysis clearly shows the effect of diminishing returns on all measures except service level as the number of spares are increased. Increasing the number of spares from zero to five increases the A_O by nearly 20%. Giving the base a further five spares only increases A_O by about 5%.

It is interesting to note that the service level is roughly a linear function of the number of spares at the base.

b. Varying The Mean Time Between Failure

Another important parameter is the failure rate of the RIs at a base. In the model this is input as a mean time between failure (MTBF) in days. Figure 4-17 shows the changes in the performance measures as the MTBF is varied from 10 days to 200 days for the three-echelon, single-base example when the number of spares at the base was held constant at ten.

The effect of diminishing returns is evident for all measures when the MTBF exceed 120 days.

c. The Effect of Limited Maintenance Capacity

The effect of changing the number of maintenance stations at a maintenance facility can easily be evaluated using the model. In the three-echelon, six-base example used to explain the statistics produced by the model, there were 14 maintenance stations at DLM. However, these were insufficient to handle the number of repairs (the average utilization was 14 with a standard deviation of zero in Figure 4-12). The effect of varying the number of maintenance stations at the DLM can be evaluated from running the model with a different number of maintenance stations at DLM and holding all other variables constant. For example, Figure 4-17 shows the effect of increasing or decreasing the number of maintenance stations at DLM by one. The data shows that by increasing the number of maintenance stations from 14 to 15, the mean repair time is reduced by 98.7 days and the maximum repair time by 103 days. Note, that even with 15 maintenance stations, all maintenance stations were fully utilized during the 10,000 day sample period.

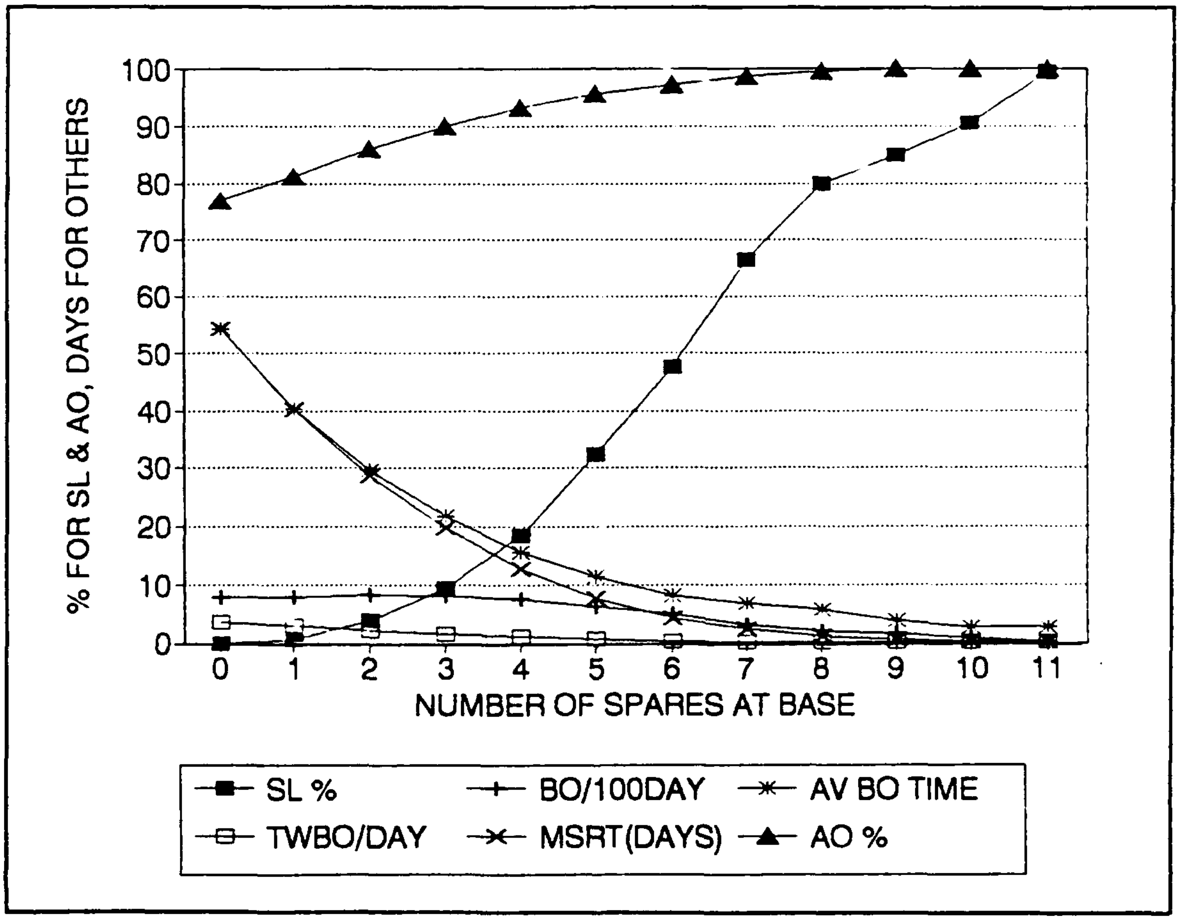


Figure 4-16. Sensitivity Analysis Showing the Change in Performance Measures as the Number of Spares are Varied at a Single Base

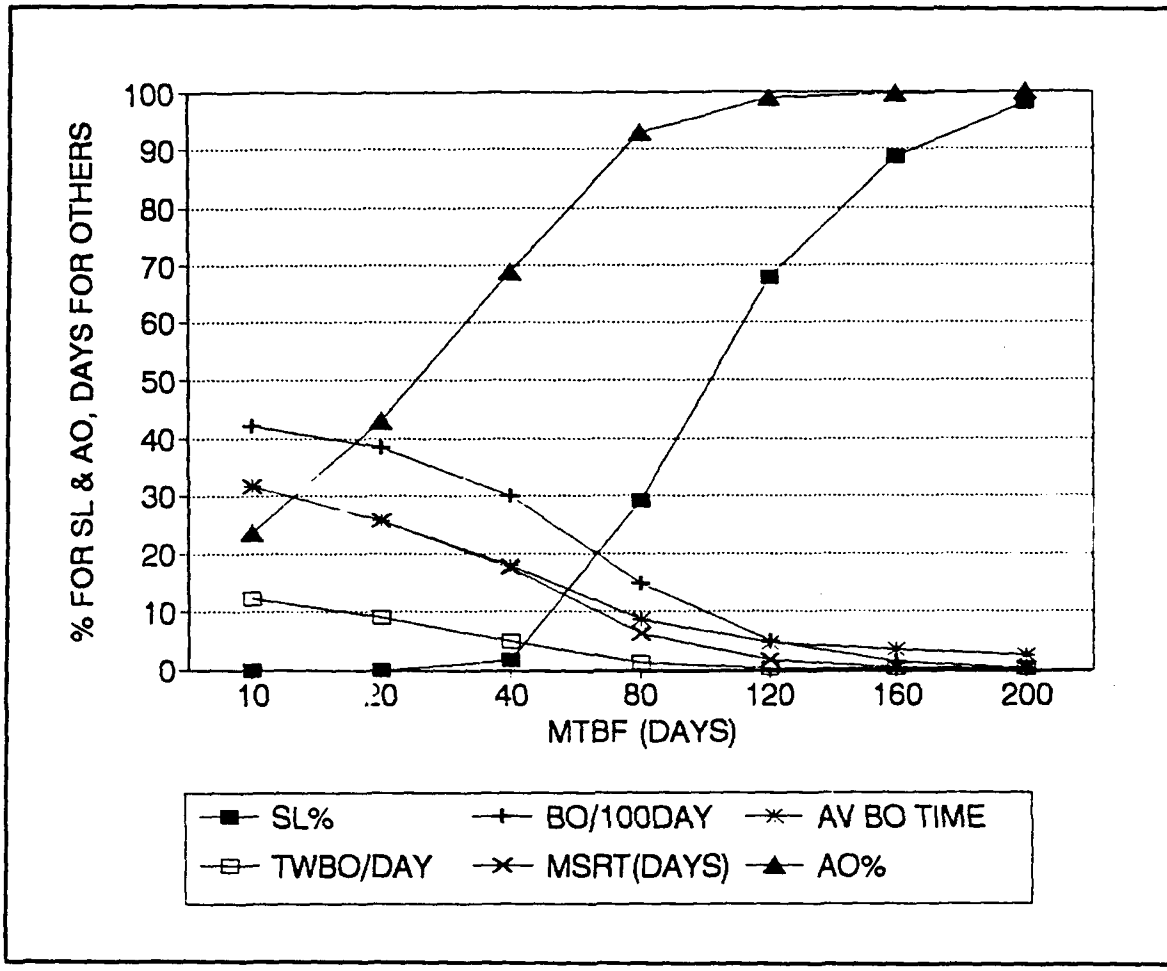


Figure 4-17. Sensitivity Analysis Showing the Change in Performance Measures at a Single Base as the MTBF is Increased

However, the effect of adding one more maintenance station had even a more dramatic effect on the measures of performance of the logistics system. Figure 4-19 shows the performance measures with 15 maintenance stations and Figure 4-14 shows the same measures for 14 maintenance stations. From the data in these figures, it can be seen that the average operational availability increased from 91.9% to 97.1% and the average service level increased from 10.3% to 50.1%.

PARAMETER	NUMBER OF MAINTENANCE STATIONS 13	14	15
REPAIR TIME			
- MEAN	514.6	426.6	327.9
- STD DEVIATION	41.7	46.4	55.3
- MINIMUM	373.1	277.8	177.9
- MAXIMUM	641.1	566.6	463.5
QUEUE STATISTICS			
LENGTH - AVERAGE	60.8	52.3	38.9
- STD DEVIATION	5.5	6.8	1.7
- MAXIMUM	76.0	68.0	59.0
AVERAGE WAITING TIME	406.1	324.5	229.1
SERVER STATISTICS			
UTILIZATION - AVERAGE	13.0	14.0	15.0
- MAXIMUM	13.0	14.0	15.0
- MINIMUM	13.0	14.0	15.0

Figure 4-18. Data Showing the Effect of Varying the Number of DLM Maintenance Stations

BASE	SL%	B ORDERS /100 DAYS	AVG BO TIME IN DAYS	TWBO BO-DAYS/DAY	MSRT IN DAYS	OPERATIONAL AVAIL%
1	50.7	4.28	8.10	0.315	3.99	97.2
2	49.7	3.88	8.56	0.302	4.31	97.2
3	53.7	1.99	9.90	0.179	4.58	98.1
4	47.3	6.39	8.61	0.500	4.54	95.2
5	49.6	3.34	9.82	0.298	4.94	97.2
6	49.4	3.55	7.99	0.258	4.05	97.9

Figure 4-19. System Statistics for a Three-Echelon, Six-Base Simulation with Lateral Resupply with 15 DLM Maintenance Stations.

D. COMPUTER TYPE AND EXECUTION TIMES

The model was developed and run on an IBM3033 mainframe computer. The model typically took about 95 seconds to execute the three-echelon, six-base example discussed in Chapter IV and defined in Figure 4-11.

The execution time of the model varies significantly depending on the configuration of the simulation. For example, a three-echelon, single-base, 20,000-day simulation executes in about 25 seconds. Also, the MTBF and maintenance factors affect the execution time as they directly affect the number of events that occur during a given simulation time. Generally, the lower the MTBF, the longer the simulation time.

SLAM II is also available in an IBM PC version. However, the current PC version has a NSET/QSET limit of 15,000 compared to 30,000 used for the model discussed in this thesis. NSET/QSET limits the maximum number of variables and entities that are available within the model. Hence, to run the model on the PC, the number of bases would need to be reduced to three or four. Based on experience of running other programs on both the mainframe and a 20 MHz, 386 PC clone, the execution time for a three-echelon, four-base configuration should be about 25 minutes.

E. ENHANCEMENTS

One of the advantages of writing the model in SLAM II, and using a modular structure, is that the model can be easily changed to evaluate features of a logistics system that it currently may not have. How to change the model to include some of the more common characteristics is outlined in the following subsections.

1. Attrition

If attrition is important, the user can easily add this feature into the model by using an attribute to record the number of times a RI is repaired. This attribute can then be tested with a conditional activity statement and the entity destroyed if the value of the attribute equals the maximum number of times a repairable can be repaired (repair limit). However, this process should not commence until the model is in steady state. This can be achieved by using a conditional activity related to the SLAM II variable TNOW which always equals the current simulation time.

2. Stochastic Shipping Times

Stochastic shipping times can be incorporated into the model by adding an additional field to each of the base parameter arrays for the standard deviation and adding a probability density function into the activity statement. For example, if the normal distribution was appropriate then the activity statement for the forward shipping of failed RIs from Base 1 to DLM could be written as:

```
ACT,RNORM(FST1D,STDS1D,5),,DLM;
```

where FST1D and STDS1D are the forward shipping time from Base 1 to DLM and its standard deviation, respectively.

3. Demand System using an Item Manager

The option to place a backorder based on knowledge from the maintenance system of where and when the next RI will complete repair can be incorporated by assigning the sample value from the maintenance repair time distributions to a global variable immediately prior to the RI entering the maintenance process. This time could then be added to the current simulation time TNOW and the resulting value would be the time at which the failed RI would be repaired and available for issue. Then, whenever a backorder occurred, a subroutine similar to LATSUP could be used to check when the next repaired RI would be available by checking all of the global variables for the RIs in maintenance. The subroutine could the add the shipping times to all global variables that meet the required time window and determine where to send the backorder. However, the routine would also have to check the number of demands already in the demand queues for all maintenance facilities.

V. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

MEEBS is a multi-echelon, multi-base, single-item, simulation model consisting of up to three maintenance echelons that can be used to evaluate the effect of a given logistics system structure on the operational availability of a number of repairable items (RIs) operating at one to six bases. The model calculates several performance measures including operational availability, mean supply response time and service level. Statistics on the flow of RIs through the system, the time spent in maintenance queues, and repair times are also provided.

The operating scenario that the model simulates can be described as follows. There are one to six independent bases operating a number of RIs. When a RI fails, it is inspected and, depending upon its estimated difficulty of repair, it is sent to one of three maintenance echelons. The lowest echelon, Operating Level Maintenance (OLM), is located at the base and is capable of fixing relatively simple failures quickly. The next echelon is the Intermediate Maintenance Level (ILM) which handles the more complex repairs. The highest echelon is the Depot Level Maintenance (DLM) which handle all complex repairs but takes a relatively long time to do so. Each echelon consists of a maintenance queue where the failed RIs wait for a free maintenance station. When a station is available, the RI is repaired and put into the store associated with that repair echelon where it is available for issue.

The inventory policy is (s-1,s) or one-for-one. When a RI fails at a base, a spare is taken from the base store to replace the failed RI and a replenishment spare is requested for the store. If the base store and the stores at ILM and DLM are all out of spares, lateral resupply from another base can be attempted if this is an allowable option. Shipping delays are incurred whenever a RI is moved between bases or echelons.

The model simulates reality in that:

- The dynamic environment where bases compete for scares resources, namely limited spares and maintenance facilities, is retained. The number of maintenance stations at each echelon and the initial number of spares in each store is determined by the user.
- The operating times and the repair times for the RIs are random variables drawn from probability density functions specified by the user.
- The sequence in which failed RIs are allocated to maintenance echelons is random. The proportion of failures repaired at each echelon is input by the user.
- RIs incur a shipping and handling delay whenever they are moved between bases or echelons. The delay can be different for every combination as determined by the user.
- Lateral resupply from other bases is available if desired.

B. CONCLUSIONS

The model developed in this thesis effort is a relatively easy-to-use simulation model that allows the user to evaluate the effects of different maintenance and inventory policies on a multi-echelon logistics system. This is achieved by providing statistics on the flow of RIs between bases and echelons and through maintenance facilities. Statistics provided include:

- The mean and the standard deviation of the number of spares and demands at each base and echelon.
- The number of RIs shipped between bases and echelons.
- The number of backorders.

- The number of times lateral resupply was attempted, the number of times it was successful, and the number of spares provided from each base.
- The mean and standard deviation of the time that RIs spend waiting for a maintenance station and the total maintenance (waiting and repair) time at all maintenance facilities.
- The mean and standard deviation of the times that the systems at each base are nonoperational awaiting a spare RI.

The model also calculates several commonly used performance measures including: operational availability; mean supply response time; time-weighted backorders; and service level. This allows the user to gain insight into how these measures relate to each other and what they mean in practical terms.

Simulation is a very effective means of evaluating multi-echelon systems as it is extremely adaptive and flexible. For example, the failure or repair distributions can be changed in a few minutes whereas most analytical models use very selective distributions and cannot handle any change. Also, simulation allows the dynamic interaction of events to be maintained. For example, the effects of lateral resupply discussed in the three-echelon, six-base example in Chapter IV would be extremely difficult to evaluate analytically.

SLAM II is ideally suited to simulating multi-echelon maintenance systems as it is oriented to the flow of entities through a network of queues and activities. SLAM II is very powerful and easy to use. In particular, its ability to effortlessly handle all timing functions and scheduling of events is impressive. However, it has a major limitation in that data associated with queue nodes and the distribution functions associated with activities must be embedded into the SLAM II commands. The ability to input this data via global variables or data arrays would significantly enhance the flexibility of SLAM II.

The model can be run on a mainframe or an IBM-type PC and is relatively quick to execute. Most of the source code for the model is written in a modular format using SLAM II. This makes the model easy to expand to include more bases or echelons, or to modify the model to include unique features of a particular system of interest.

C. RECOMMENDATIONS

The model requires further work to validate its operation in all configurations, to present the data from the model in a more readily usable format and to fully develop its potential applications. In particular, the addition of a subroutine that would interface the model with a graphing program would allow the data collected on the performance measures during each sample period to be quickly plotted and available for review and evaluation.

Lateral resupply and the configuration of maintenance echelons are critical elements of a logistics system. Optimization of these elements can significantly improve the operational availability of the operating RIs and may also reduce the total cost of logistics support. Therefore, the use of the model to study both of these elements under varying conditions is recommended.

APPENDIX A. LOGIC CHARTS FOR THE NETWORK SECTION OF THE MODEL

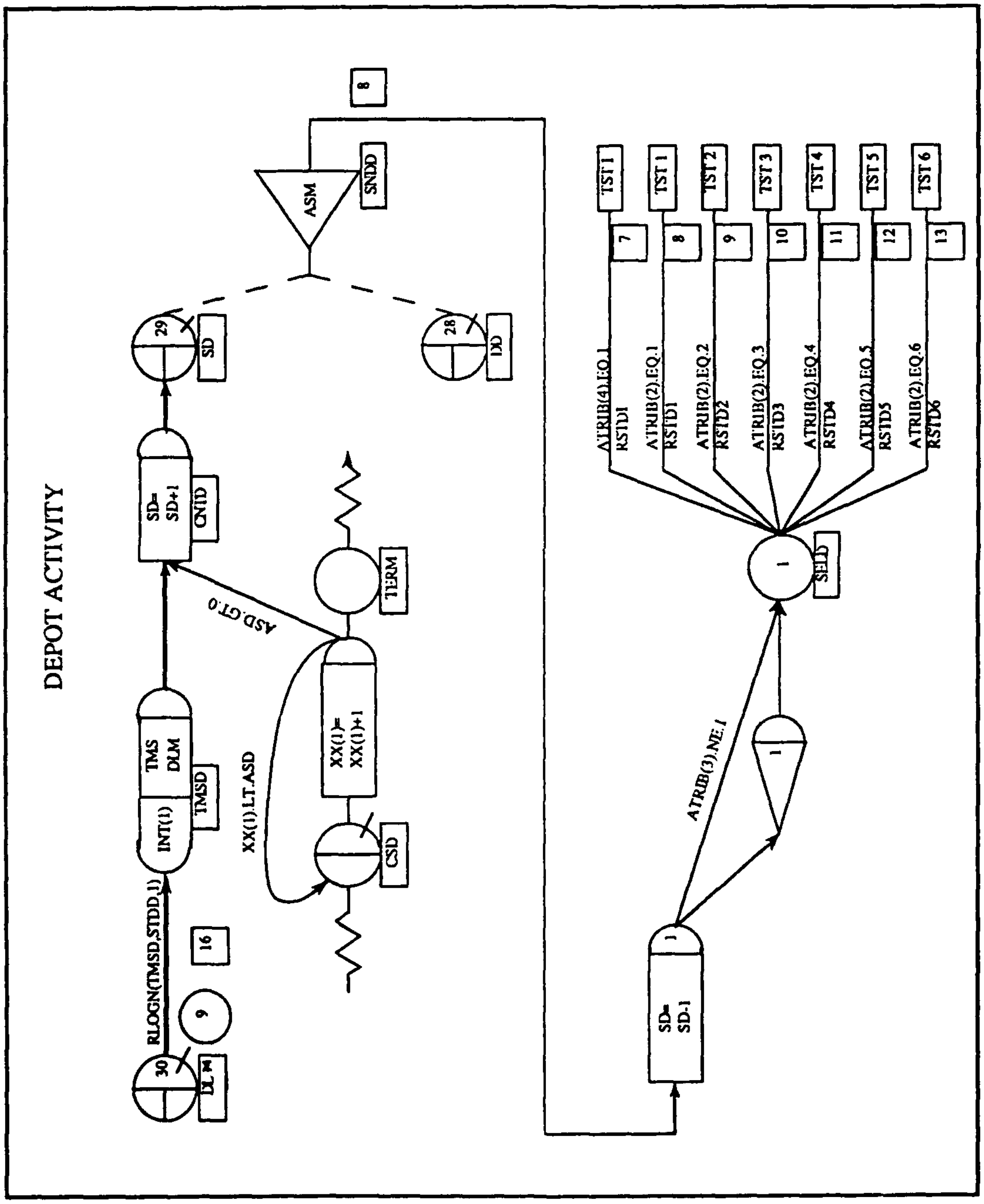


Figure A-1. Depot Activity Consisting of: DLM; Creation of DLM Spares; Cperation of the DLM Store; and Selection of the Base or ILM Demanding a Spare

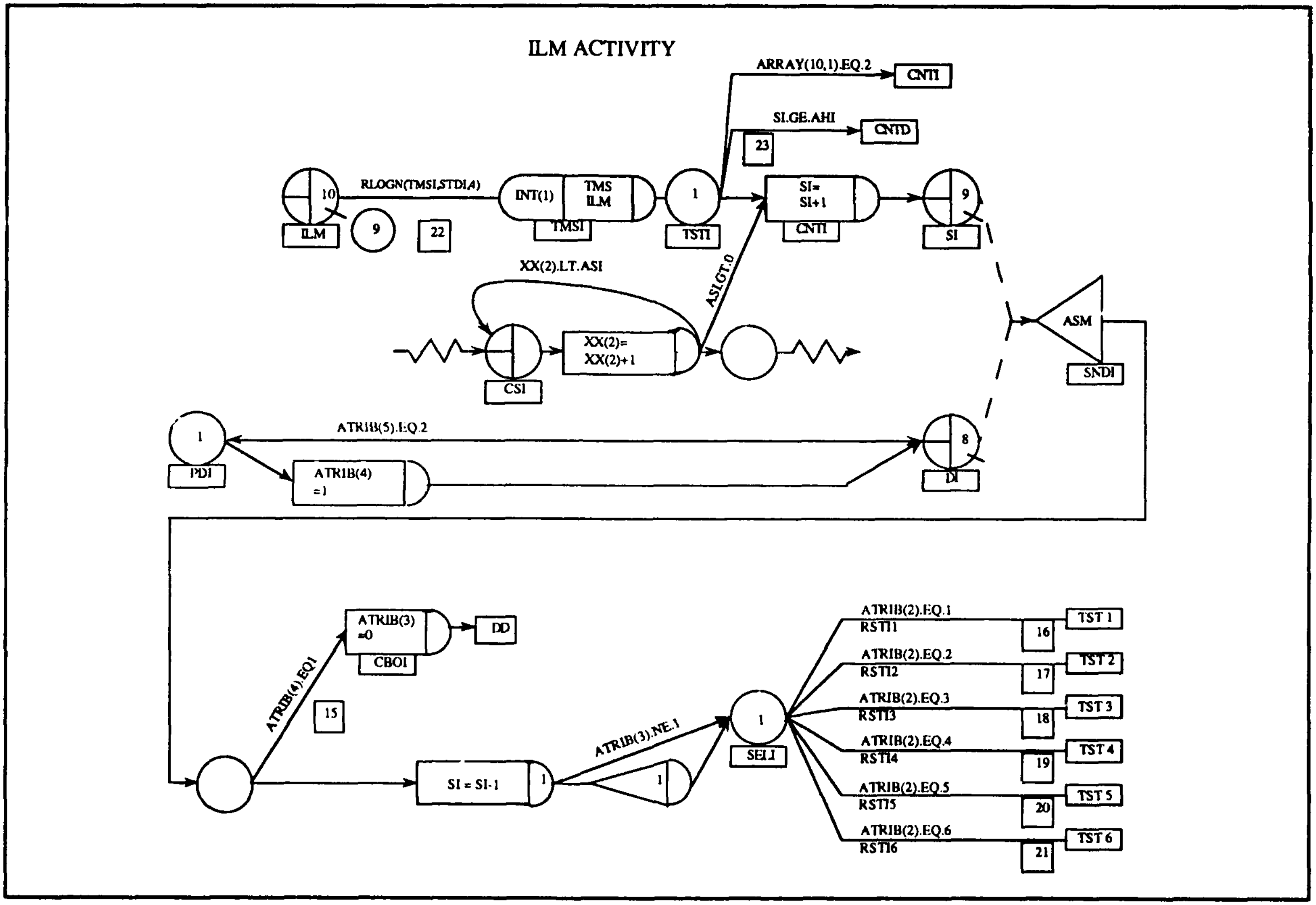


Figure A-2. Intermediate Level Repair Activity Consisting of ILM; Creation of ILM Spares; Operation of the ILM Store; and Selection of the Base Demanding a Spare

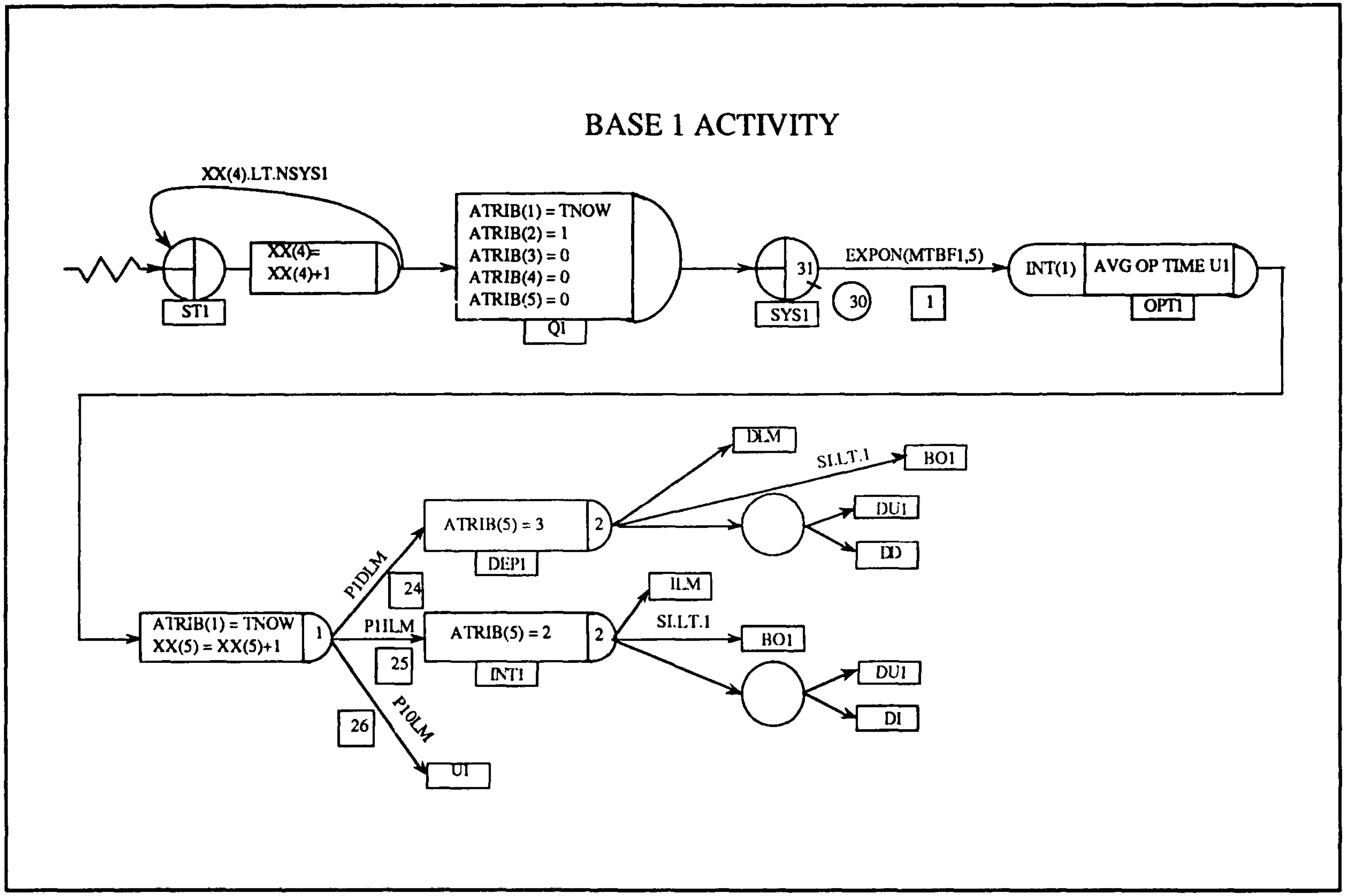


Figure A-3. Creation and Operation of Recoverable Items (RIs) at Base 1, the Selection of a Maintenance Facility for a Failed RI, and the Initialization of a Demand for a Replacement Spare

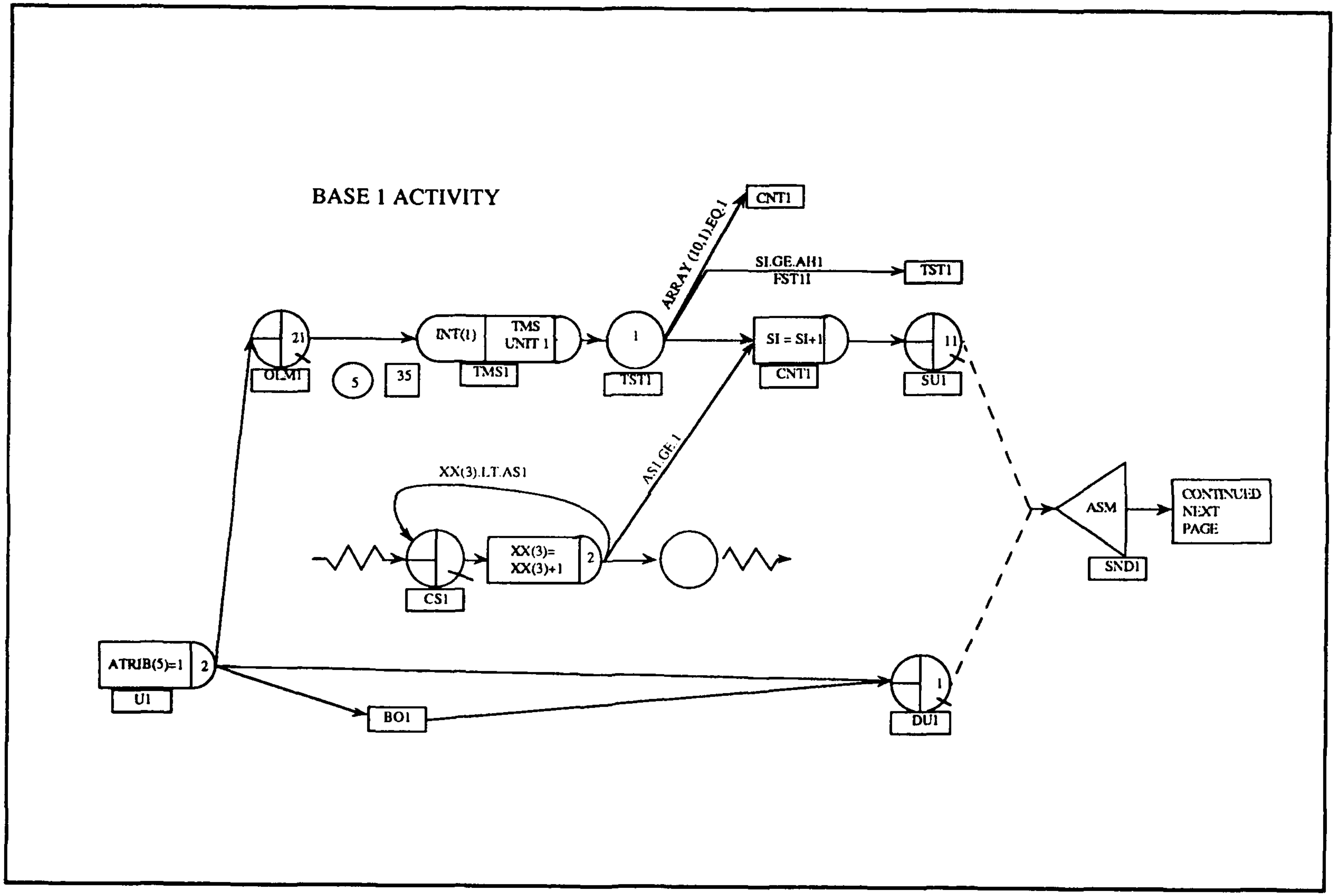


Figure A-4. Base 1 Activity Creation of Authorized Spares; Operating Level Maintenance, and Demand/Backorder Activity

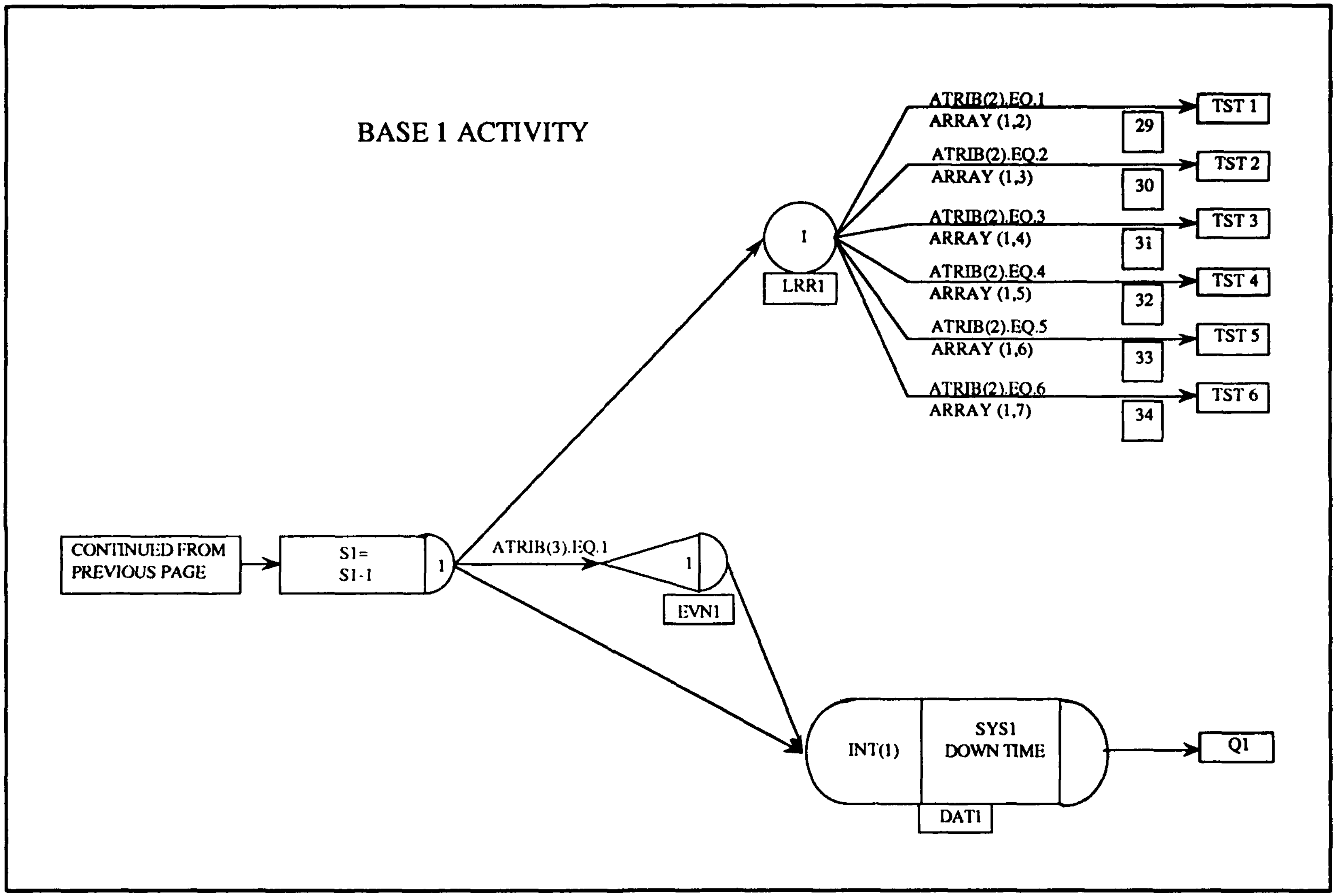


Figure A-5. Base 1 Activity. Decrement Spares Counter; Cancel Backorders; Collect System Down Time Statistics; and Send Spare to the Base Requesting Lateral Resupply

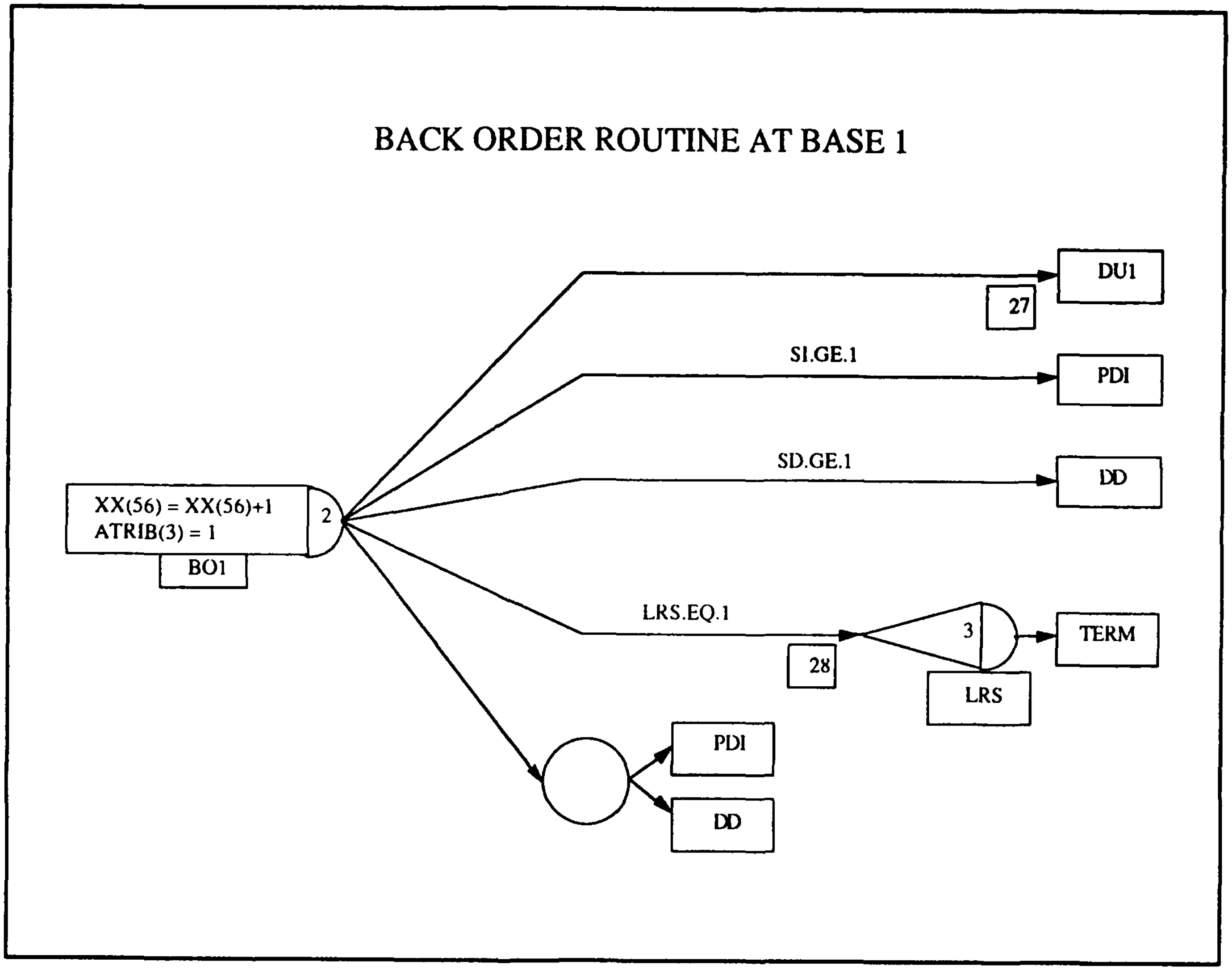


Figure A-6. Backorder Routine at Base 1

APPENDIX B. SLAM II SOURCE CODE FOR THE NETWORK SECTION OF THE MODEL

```
GEN,CORNWALL,S6 3ECHELON 6 BASE,06/13/90,1,YES,YES;
LIMITS,36,10,700;
;
;**********************************************************************
;                  COMMENTS ON SIMULATION
;                  **********************
;
; DATE: 13 JUNE 90
; TIME: 1220
;
; NUMBER OF BASES: 6
; LATERAL RESUPPLY: NO
; NUMBER OF MAINTENANCE LEVELS: 3
; RUN TIME: 20,000 DAYS
; SAMPLE TIME: 1,000 DAYS
;                                           MAINTENANCE   DATA
;                                -------------------------------------
; BASE SPARES #SYSTEMS MTBF #SERVERS TMS STD  P(DLM) P(ILM) P(OLM)
; ---- ------ -------- ---- -------- --- ---  ------ ------ ------
; DLM     3                     14      90  14
; ILM     4                      9      30   6
;   1    10      16     200      5      10   3     .4      .3      .3
;   2    10      16     220      5      10   3     .4      .3      .3
;   3    10      16     400      5      10   3     .4      .3      .3
;   4    10      16     140      5      10   3     .4      .3      .3
;   5    10      16     280      5      10   3     .4      .3      .3
;   6    10      16     270      5      10   3     .4      .3      .3
;
; SHIPPING TIMES
; --------------
;
;          ILM      DLM             LRT
; ----  -------  -------  -----------------------
; BASE  FST RST  FST RST   1   2   3   4   5   6
; ----  --- ---  --- ---  --- --- --- --- --- ---
;
;   1    2   2    4   4    -   1   1   1   1   1
;   2    2   2    4   4    1   -   1   1   1   1
;   3    2   2    4   4    1   1   -   1   1   1
;   4    2   2    4   4    1   1   1   -   1   1
;   5    2   2    4   4    1   1   1   1   -   1
```

```
;   6    2   2    4   4    1   1   1   1   1   -
;
; ILM    -   -    4   4
; DLM    2   2    -   -
;
; COMMENTS:  DATA RUN 31
;
;
;
;*******************************************************************
;INITIALIZE GLOBAL VARIABLES
;--------------------------
;XX(27)=TMSD, XX(28)=STDD, XX(29)=TMSI, XX(30)=STDI
;XX(31)=TMS1, XX(32)=STD1, XX(33)=MTBF1
;XX(34)=TMS2, XX(35)=STD2, XX(36)=MTBF2
;XX(37)=TMS3, XX(38)=STD3, XX(39)=MTBF3
;XX(40)=TMS4, XX(41)=STD4, XX(42)=MTBF4
;XX(43)=TMS5, XX(44)=STD5, XX(45)=MTBF5
;XX(46)=TMS6, XX(47)=STD6, XX(48)=MTBF6
;---------------------------------------------
INTCL,XX(27)=90, XX(28)=18, XX(29)=30, XX(30)=6,
      XX(31)=10, XX(32)=3, XX(33)=200,
      XX(34)=10, XX(35)=3, XX(36)=220,
      XX(37)=10, XX(38)=3, XX(39)=400;
INTCL,XX(40)=10, XX(41)=3, XX(42)=140,
      XX(43)=10, XX(44)=3, XX(45)=280,
      XX(46)=10, XX(47)=3, XX(48)=270;
;
;BASE 1 DATA. (1-7) NSYS1, LRT11,LRT12,LRT13,LRT14,LRT15,LRT16,
;-------------------------------------------------------------
;(8-10) P1DLM,P1ILM,P1OLM, (11-16) FST1I,RSTI1,FST1D,RSTD1,AH1,AS1
;----------------------------------------------------------------
ARRAY(1,16)/16,0,1,1,1,1,1,0.4,0.3,0.3.2,2,4,4,10,10;
;
;BASE 2 DATA. (1-7) NSYS2, LRT21,LRT22,LRT23,LRT24,LRT25,LRT26,
;-------------------------------------------------------------
;(8-10) P2DLM,P2ILM,P2OLM, (11-16) FST2I,RSTI2,FST2D,RSTD2,AH2,AS2
;----------------------------------------------------------------
ARRAY(2,16)/16,1,0,1,1,1,1,0.4,0.3,0.3,2,2,4,4,10,10;
;
;
;BASE 3 DATA. (1-7) NSYS3, LRT31,LRT32,LRT33,LRT34,LRT35,LRT36,
;-------------------------------------------------------------
;(8-10) P3DLM,P3ILM,P3OLM, (11-16) FST3I,RSTI3,FST3D,RSTD3,AH3,AS3
;----------------------------------------------------------------
ARRAY(3,16)/16,1,1,0,1,1,1,0.4,0.3,0.3,2,2,4,4,10,10;
;
;BASE 4 DATA. (1-7) NSYS4, LRT41,LRT42,LRT43,LRT44,LRT45,LRT46,
;-------------------------------------------------------------
;(8-10) P4DLM,P4ILM,P4OLM, (11-16) FST4I,RSTI4,FST4D,RSTD4,AH4,AS4
;----------------------------------------------------------------
```

```
ARRAY(4,16)/16,1,1,1,0,1,1,0.4,0.3,0.3,2,2,4,4,10,10;
;
;BASE 5 DATA. (1-7) NSYS5, LRT51,LRT52,LRT53,LRT54,LRT55,LRT56,
;---------------------------------------------------------------
;(8-10) P5DLM,P5ILM,P5OLM, (11-16) FST5I,RSTI5,FST5D,RSTD5,AH5,AS5
;------------------------------------------------------------------
ARRAY(5,16)/16,1,1,1,1,0,1,0.4,0.3,0.3,2,2,4,4,10,10;
;
;BASE 6 DATA. (1-7) NSYS6, LRT61,LRT62,LRT63,LRT64,LRT65,LRT66,
;---------------------------------------------------------------
;(8-10) P6DLM,P6ILM,P6OLM, (11-16) FST6I,RSTI6,FST6D,RSTD6,AH6,AS6
;------------------------------------------------------------------
ARRAY(6,16)/16,1,1,1,1,1,0,0.4,0.3,0.3,2,2,4,4,10,10;
;
;ILM DATA. FSTID, RSTDI, AHI, ASI
;--------------------------------
ARRAY(8,4)/2,2,4,4;
;
;DLM DATA. ASD
;-------------
ARRAY(9,1)/3;
;
;SELECT OPTIONS
;--------------
;FIELD1 = # MAINTENANCE LEVELS. 3=3 LEVELS, 2=2 LEVELS, 1=1 LEVEL
;      2 = # BASES (1...6)
;      3 = LATERAL RESUPPLY (= 1 SET, 0 = NOT SET).
;      4 = TIME THE SLAM II STAT ARRAYS ARE CLEARED
;      5 = END TIME FOR SIMULATION RUN
; NOTE: VALUES FOR FIELDS 4 & 5 MUST BE A MULTIPLE OF THE SAMPLE TIME
;
ARRAY(10,5)/3,6,0,10000,20000;
;
;*********************************************************************
; NOTE: THE PROGRAM WAS WRITTEN USING THE TERM "UNIT" INSTEAD OF "BASE"
;      HENCE THE LETTER "U" IS USED IN MANY VARIABLES TO SIGNIFY A BASE
;
EQUIVALENCE/XX(19),SD;                  = SPARES DEPOT
EQUIVALENCE/XX(20),SI;                  = SPARES ILM
EQUIVALENCE/XX(21),S1;                  = SPARES BASE 1
EQUIVALENCE/XX(22),S2;                  = SPARES BASE 2
EQUIVALENCE/XX(23),S3;                  = SPARES BASE 3
EQUIVALENCE/XX(24),S4;                  = SPARES BASE 4
EQUIVALENCE/XX(25),S5;                  = SPARES BASE 5
EQUIVALENCE/XX(26),S6;                  = SPARES BASE 6
EQUIVALENCE/XX(27),TMSD;                = TMS DEPOT
EQUIVALENCE/XX(28),STDD;                = STANDARD DEVIATION OF TMS DLM
EQUIVALENCE/XX(29),TMSI;                = TMS ILM
EQUIVALENCE/XX(30),STDI;                = STANDARD DEVIATION OF TMS ILM
EQUIVALENCE/XX(31),TMS1;                = TMS BASE 1
EQUIVALENCE/XX(32),STD1;                = STANDARD DEVIATION OF TMS 1
```

```
EQUIVALENCE/XX(33),MTBF1;          = MTBF/SYSTEM (IN DAYS) BASE 1
EQUIVALENCE/XX(34),TMS2;           = TMS BASE 2
EQUIVALENCE/XX(35),STD2;           = STANDARD DEVIATION OF TMS 2
EQUIVALENCE/XX(36),MTBF2;          = MTBF/SYSTEM (IN DAYS) BASE 2
EQUIVALENCE/XX(37),TMS3;           = TMS BASE 3
EQUIVALENCE/XX(38),STD3;           = STANDARD DEVIATION OF TMS 3
EQUIVALENCE/XX(39),MTBF3;          = MTBF/SYSTEM (IN DAYS) BASE 3
EQUIVALENCE/XX(40),TMS4;           = TMS BASE 4
EQUIVALENCE/XX(41),STD4;           = STANDARD DEVIATION OF TMS 4
EQUIVALENCE/XX(42),MTBF4;          = MTBF/SYSTEM (IN DAYS) BASE 4
EQUIVALENCE/XX(43),TMS5;           = TMS BASE 5
EQUIVALENCE/XX(44),STD5;           = STANDARD DEVIATION OF TMS 5
EQUIVALENCE/XX(45),MTBF5;          = MTBF/SYSTEM (IN DAYS) BASE 5
EQUIVALENCE/XX(46),TMS6;           = TMS BASE 6
EQUIVALENCE/XX(47),STD6;           = STANDARD DEVIATION OF TMS 6
EQUIVALENCE/XX(48),MTBF6;          = MTBF/SYSTEM (IN DAYS) BASE 6
EQUIVALENCE/ARRAY(1,1),NSYS1;      = NUMBER OF SYSTEMS AT BASE1
EQUIVALENCE/ARRAY(1,8),P1DLM;      = P(U1 FAILURE REPAIRED AT DLM)
EQUIVALENCE/ARRAY(1,9),P1ILM;      = P(U1 FAILURE REPAIRED AT ILM)
EQUIVALENCE/ARRAY(1,10),P1OLM;     = P(U1 FAILURE REPAIRED AT OLM)
EQUIVALENCE/ARRAY(1,11),FST1I;     = FST FROM BASE 1 TO ILM
EQUIVALENCE/ARRAY(1,12),RSTI1;     = RST FROM ILM TO BASE 1
EQUIVALENCE/ARRAY(1,13),FST1D;     = FST FROM BASE 1 TO DLM
EQUIVALENCE/ARRAY(1,14),RSTD1;     = RST FROM DEPOT TO BASE 1
EQUIVALENCE/ARRAY(1,15),AH1;       = AUTHORIZED (SPARES) HOLDING U1
EQUIVALENCE/ARRAY(1,16),AS1;       = AUTHORIZED (ISSUED) SPARES U1
EQUIVALENCE/ARRAY(2,1),NSYS2;      = NUMBER OF SYSTEMS AT BASE1
EQUIVALENCE/ARRAY(2,8),P2DLM;      = P(U2 FAILURE REPAIRED AT DLM)
EQUIVALENCE/ARRAY(2,9),P2ILM;      = P(U2 FAILURE REPAIRED AT ILM)
EQUIVALENCE/ARRAY(2,10),P2OLM;     = P(U2 FAILURE REPAIRED AT OLM)
EQUIVALENCE/ARRAY(2,11),FST2I;     = FST FROM BASE 2 TO ILM
EQUIVALENCE/ARRAY(2,12),RSTI2;     = RST FROM ILM TO BASE 2
EQUIVALENCE/ARRAY(2,13),FST2D;     = FST FROM BASE 2 TO DLM
EQUIVALENCE/ARRAY(2,14),RSTD2;     = RST FROM DEPOT TO BASE 2
EQUIVALENCE/ARRAY(2,15),AH2;       = AUTHORIZED (SPARES) HOLDING U2
EQUIVALENCE/ARRAY(2,16),AS2;       = AUTHORIZED (ISSUED) SPARES U2
EQUIVALENCE/ARRAY(3,1),NSYS3;      = NUMBER OF SYSTEMS AT BASE3
EQUIVALENCE/ARRAY(3,8),P3DLM;      = P(U3 FAILURE REPAIRED AT DLM)
EQUIVALENCE/ARRAY(3,9),P3ILM;      = P(U3 FAILURE REPAIRED AT ILM)
EQUIVALENCE/ARRAY(3,10),P3OLM;     = P(U3 FAILURE REPAIRED AT OLM)
EQUIVALENCE/ARRAY(3,11),FST3I;     = FST FROM BASE 3 TO ILM
EQUIVALENCE/ARRAY(3,12),RSTI3;     = RST FROM ILM TO BASE 3
EQUIVALENCE/ARRAY(3,13),FST3D;     = FST FROM BASE 3 TO DLM
EQUIVALENCE/ARRAY(3,14),RSTD3;     = RST FROM DEPOT TO BASE 3
EQUIVALENCE/ARRAY(3,15),AH3;       = AUTHORIZED (SPARES) HOLDING U3
EQUIVALENCE/ARRAY(3,16),AS3;       = AUTHORIZED (ISSUED) SPARES U3
EQUIVALENCE/ARRAY(4,1),NSYS4;      = NUMBER OF SYSTEMS AT BASE4
EQUIVALENCE/ARRAY(4,8),P4DLM;      = P(U4 FAILURE REPAIRED AT DLM)
EQUIVALENCE/ARRAY(4,9),P4ILM;      = P(U4 FAILURE REPAIRED AT ILM)
EQUIVALENCE/ARRAY(4,10),P4OLM;     = P(U4 FAILURE REPAIRED AT OLM)
EQUIVALENCE/ARRAY(4,11),FST4I;     = FST FROM BASE 4 TO ILM
```

```
EQUIVALENCE/ARRAY(4,12),RSTI4;          = RST FROM ILM TO BASE 4
EQUIVALENCE/ARRAY(4,13),FST4D;          = FST FROM BASE 4 TO DLM
EQUIVALENCE/ARRAY(4,14),RSTD4;          = RST FROM DEPOT TO BASE 4
EQUIVALENCE/ARRAY(4,15),AH4;            = AUTHORIZED (SPARES) HOLDING U4
EQUIVALENCE/ARRAY(4,16),AS4;            = AUTHORIZED (ISSUED) SPARES U4
EQUIVALENCE/ARRAY(5,1),NSYS5;           = NUMBER OF SYSTEMS AT BASE5
EQUIVALENCE/ARRAY(5,8),P5DLM;           = P(U5 FAILURE REPAIRED AT DLM)
EQUIVALENCE/ARRAY(5,9),P5ILM;           = P(U5 FAILURE REPAIRED AT ILM)
EQUIVALENCE/ARRAY(5,10),P5OLM;          = P(U5 FAILURE REPAIRED AT OLM)
EQUIVALENCE/ARRAY(5,11),FST5I;          = FST FROM BASE 5 TO ILM
EQUIVALENCE/ARRAY(5,12),RSTI5;          = RST FROM ILM TO BASE 5
EQUIVALENCE/ARRAY(5,13),FST5D;          = FST FROM BASE 5 TO DLM
EQUIVALENCE/ARRAY(5,14),RSTD5;          = RST FROM DEPOT TO BASE 5
EQUIVALENCE/ARRAY(5,15),AH5;            = AUTHORIZED (SPARES) HOLDING U5
EQUIVALENCE/ARRAY(5,16),AS5;            = AUTHORIZED (ISSUED) SPARES U5
EQUIVALENCE/ARRAY(6,1),NSYS6;           = NUMBER OF SYSTEMS AT BASE6
EQUIVALENCE/ARRAY(6,8),P6DLM;           = P(U6 FAILURE REPAIRED AT DLM)
EQUIVALENCE/ARRAY(6,9),P6ILM;           = P(U6 FAILURE REPAIRED AT ILM)
EQUIVALENCE/ARRAY(6,10),P6OLM;          = P(U6 FAILURE REPAIRED AT OLM)
EQUIVALENCE/ARRAY(6,11),FST6I;          = FST FROM BASE 6 TO ILM
EQUIVALENCE/ARRAY(6,12),RSTI6;          = RST FROM ILM TO BASE 6
EQUIVALENCE/ARRAY(6,13),FST6D;          = FST FROM BASE 6 TO DLM
EQUIVALENCE/ARRAY(6,14),RSTD6;          = RST FROM DEPOT TO BASE 6
EQUIVALENCE/ARRAY(6,15),AH6;            = AUTHORIZED (SPARES) HOLDING U6
EQUIVALENCE/ARRAY(6,16),AS6;            = AUTHORIZED (ISSUED) SPARES U6
EQUIVALENCE/ARRAY(8,1),FSTID;           = FST FROM ILM TO DLM
EQUIVALENCE/ARRAY(8,2),RSTDI;           = RST FROM DLM TO ILM
EQUIVALENCE/ARRAY(8,3),AHI;             = AUTHORIZED (SPARES) HOLDING ILM
EQUIVALENCE/ARRAY(8,4),ASI;             = AUTHORIZED (ISSUED) SPARES ILM
EQUIVALENCE/ARRAY(9,1),ASD;             = AUTHORIZED (ISSUED) SPARES DLM
EQUIVALENCE/ARRAY(10,3),LRS;            = LATERAL RESUPPLY OPTION
;
;DEFINE ATTRIBUTES
;-----------------
;       INITIAL SETTING FOR ALL ATTRIBUTES = 0
;
;       1 = TNOW
;       2 = BASE FLAG (SOURCE OF FAILURE), 1 = BASE 1...6 = BASE 6
;       3 = BASE DEMAND FLAG, 0=REPLENISMENT, 1=BACKORDER
;       4 = ILM DEMAND FLAG, 0=NO, 1=REPLENISHMENT
;       5 = ALLOCATED REPAIR LEVEL, 1=OLM, 2=ILM, 3=DLM
;       6 = LATERAL RESUPPLY FLAG, -1=RESUPPLY ACHIEVED, 1= NO RESUPPLY
;       7 = TMS
;
; DEFINE GLOBAL (XX) VARIABLES
; ---------------------------
;  1-14 INITIALIZATION COUNTERS
; 19-26 SPARES LEVELS
; 27-48 TMS & STD, MTBF
; 50-55 # DEMANDS
; 56-61 # BACKORDERS
```

```
; 62-68 TIME AWAITING BACKORDERS
;
NETWORK;
;
; DLM ACTIVITY
; ************
;
; CREATE AUTHORIZED DLM SPARES
; ---------------------------
CSD      CREATE;
         ASSIGN,XX(1)=XX(1)+1;
         ACT,,XX(1).LT.ASD,CSD;
         ACT,,ASD.GT.0,CNTD;                #DLM SPARES
         ACT;
TERM     GOON;
         TERMINATE;
;
; DLM DEMAND ACTIVITY
; ------------------
DD      QUEUE(28),,,,SNDD;                   PROCESS DEMAND
SD      QUEUE(29),,,,SNDD;                   DLM STORE
SNDD    SELECT,ASM,,,DD,SD;                  ASSEMBLE ORDER
        ACT;
;
;       TAKE SPARE, SEND TO ILM OR BASE
;       ------------------------------
        ASSIGN,SD=SD-1,1;
        ACT,,ATRIB(3).NE.1,SELD;             BO DEMAND?
        ACT;                                 YES
        EVENT,1;                             CANCEL DUPLICATE BACKORDERS
        ACT;
SELD    GOON,1;                              SELECT DEMANDING BASE
        ACT/7,RSTDI,ATRIB(4).EQ.1,TSTI;      # SD TO ILM
        ACT/8,RSTD1,ATRIB(2).EQ.1,TST1;      # DLM - U1
        ACT/9,RSTD2,ATRIB(2).EQ.2,TST2;      # DLM - U2
        ACT/10,RSTD3,ATRIB(2).EQ.3,TST3;     # DLM - U3
        ACT/11,RSTD4,ATRIB(2).EQ.4,TST4;     # DLM - U4
        ACT/12,RSTD5,ATRIB(2).EQ.5,TST5;     # DLM - U5
        ACT/13,RSTD6,ATRIB(2).EQ.6,TST6;     # DLM - U6
;
; DLM MAINTENANCE ACTIVITY
; -----------------------
DLM     ASSIGN,ATRIB(7)=TNOW;
DLMQ    QUEUE(30);                           AWAIT REPAIR
        ACT(14)/14,RLOGN(TMSD,STDD,1);       DLM  REPAIR
TMSD    COLCT,INT(7),TMS DLM,40/0/20;
CNTD    ASSIGN,SD=SD+1;                      INC COUNTER
        ACT,,,SD;                            #INTO DSTORE
;
; ILM ACTIVITY
; ************
```

```
;
; CREATE AUTHORIZED ILM SPARES
; ----------------------------
CSI      CREATE;
         ASSIGN,XX(2)=XX(2)+1;
         ACT,,XX(2).LT.ASI,CSI;
         ACT,,ASI.GT.0,CNTI;                 # ILM SPARES
         ACT;
         GOON;
         TERMINATE;
;
; ILM DEMAND ACTIVITY
; -------------------
;
;       SEND ILM SPARE TO REPLACE BASE SPARE
;       ------------------------------------
PDI     GOON,1;                              CHECK MAINT LEVEL FLAG
        ACT,,ATRIB(5).EQ.2,DI;               HAVE FAILED RI
        ACT;                                 ELSE
        ASSIGN,ATRIB(4)=1;                   SET RESUP ILM FLAG
DI      QUEUE(8),,,,SNDI;                    PROCESS DEMAND
SI      QUEUE(9),,,,SNDI;                    ILM STORE
SNDI    SELECT,ASM,,,DI,SI;                  ASSEMBLE ORDER
        ACT;
        GOON;
        ACT/15,,ATRIB(4).EQ.1,CBOI;          RESUP I FM D
        ACT;
;
;       TAKE ILM SPARE, SEND TO BASE
;       ----------------------------
        ASSIGN,SI=SI-1,1;
        ACT,,ATRIB(3).NE.1,SELI;             BO DEMAND?
        ACT;                                 YES
        EVENT,1;                             CANCEL DUPLICATE BACKORDERS
        ACT,,,SELI;
CBOI    ASSIGN,ATRIB(3)=0;                   CANCEL BO FLAG
        ACT,,,DD;                            RESUP ILM FROM DLM
SELI    GOON,1;                              SELECT DEMANDING BASE
        ACT/16,RSTI1,ATRIB(2).EQ.1,TST1;      # ILM - U1
        ACT/17,RSTI2,ATRIB(2).EQ.2,TST2;      # ILM - U2
        ACT/18,RSTI3,ATRIB(2).EQ.3,TST3;      # ILM - U3
        ACT/19,RSTI4,ATRIB(2).EQ.4,TST4;      # ILM - U4
        ACT/20,RSTI5,ATRIB(2).EQ.5,TST5;      # ILM - U5
        ACT/21,RSTI6,ATRIB(2).EQ.6,TST6;      # ILM - U6
;
; ILM MAINTENANCE ACTIVITY
; ------------------------
ILM     ASSIGN,ATRIB(7)=TNOW;
ILMQ    QUEUE(10);                           AWAIT REPAIR
        ACT(9)/22,RLOGN(TMSI,STDI,4);        ILM REPAIR
TMSI    COLCT,INT(7),TMS ILM,25/0/3;
```

```
TSTI    GOON,1;                                         CHECK LEVELS OF MAINTENANCE
        ACT,,ARRARY(10,1).EQ.2,CNTI;                    2 LEVELS, BYPASS ASI TEST
        ACT/23,FSTID,SI.GE.AHI,CNTD;                    EX SI TO DLM
        ACT;                                            ELSE
CNTI    ASSIGN,SI=SI+1;                                 PUT REPAIRED RI INTO STORE
        ACT,,,SI;
;
;
; BASE 1 ACTIVITY
; ***************
;
; CREATE AUTHORIZED BASE SPARES
; ----------------------------
CS1      CREATE;
         ASSIGN,XX(3)=XX(3)+1;
         ACT,,XX(3).LT.AS1,CS1;
         ACT,,AS1.GT.0,CNT1;
         ACT;
         GOON;
         TERMINATE;
;
; CREATE OPERATING SYSTEMS. NUMBER OF SYSTEMS = NSYS1
; ------------------------------------------------
ST1      CREATE;
         ASSIGN,XX(4)=XX(4)+1;
         ACT,,XX(4).LT.NSYS1,ST1;
         ACT,,NSYS1.GE.1,Q1;
         ACT,,,TERM;
;
; GENERATE FAILURES AT BASE
; ------------------------
;
Q1       ASSIGN,ATRIB(1)=TNOW,ATRIB(2)=1,ATRIB(3)=0,ATRIB(4)=0,
                ATRIB(5)=0,ATRIB(6)=0;
         ACT;
SYS1     QUEUE(31);
         ACT(20)/1,EXPON(MTBF1,2);               OP SYS U1
OPT1     COLCT,INT(1),AVG OP TIME B1,30/30/20;
         ACT;
;
; ALLOCATE FAILURE TO REPAIR LEVEL
; ------------------------------
;
         ASSIGN,ATRIB(1)=TNOW,XX(50)=XX(50)+1,1;CNT # DEMANDS
         ACT/24,,P1DLM,DEP1;DLM REPAIR 1;
         ACT/25,,P1ILM,INT1;ILM REPAIR 1;
         ACT/26,,P1OLM,U1;OLM REPAIR 1;
;
DEP1     ASSIGN,ATRIB(5)=3,2;                           SET MAINTENANCE LEVEL FLAG
         ACT,FST1D,,DLM;                                TO DLM REPAIR QUEUE
         ACT,,S1.LT.1,BO1;                              NO BASE SPARE, BACKORDER
```

```
            ACT;                                 ELSE
            GOON;                                HAVE BASE SPARE
            ACT,,,DU1;                           FIX DOWN SYSTEM
            ACT,,,DD;                            RESUP FROM ILM
;
INT1        ASSIGN,ATRIB(5)=2,2;                 SET MAINTENANCE LEVEL FLAG
            ACT,FST1I,,ILM;                      RI TO ILM REPAIR QUEUE
            ACT,,S1.LT.1,BO1;                    NO BASE SPARE, BACKORDER
            ACT;                                 ELSE
            GOON;                                HAVE BASE SPARE
            ACT,,,DU1;                           FIX DOWN SYSTEM
            ACT,,,DI;                            RESUP FROM ILM
;
; BASE DEMAND ACTIVITY
; --------------------
U1         ASSIGN,ATRIB(5)=1,2;
           ACT,,,OLM1;                           FAILED RI TO OLM QUEUE
;
;          REPLACE FAILED RI WITH SPARE FROM BASE STORE
;          --------------------------------------------
           ACT,,S1.GE.1,DU1;                     FIX SYSTEM
           ACT;                                  ELSE
;
;          NO BASE SPARE, BACKORDER
;          -------------------------
BO1        ASSIGN,ATRIB(3)=1,XX(56)=XX(56)+1,2;  SET BO FLAG & CNT BO'S
           ACT/27,,,DU1;#BO BASE 1;              SUBMIT BO AT BASE
           ACT,,SI.GE.1,PDI;
           ACT,,SD.GE.1,DD;
;
;          LATERAL RESUPPLY OPTION
;          -----------------------
           ACT/28,,LRS.EQ.1,LRS;        U1-TRY LRS
           ACT;                         NO SPARE AT ILM, DLM OR OTHER BASES
           GOON,2;                      SEND BO TO BOTH ILM & DLM & WAIT
           ACT,,,PDI;
           ACT,,,DD;
LRS        EVENT,3;
           ACT,,,TERM;
;
;          BASE STORE
;          ----------
DU1        QUEUE(1),,,,SND1;                     PROCESS DEMAND
SU1        QUEUE(11),,,,SND1;                    BASE1 STORE
SND1       SELECT,ASM,,,DU1,SU1;                 ASSEMBLE ORDER
           ACT;
;
;          DECREMENT SPARES
;          ---- -----------
           ASSIGN,S1=S1-1,1;
           ACT,,ATRIB(6).LT.0,LRR1;              LATERAL RESUPPLY REQUEST?
```

```
        ACT,,ATRIB(3).EQ.1,EVN1;                 BO REQUEST?
        ACT,,,DAT1;                              ROUTINE DEMAND
LRR1    GOON,1;                                  SHIP TO REQUESTING BASE
        ACT,ARRAY(1,2),ATRIB(2).EQ.1,TST1;              LRS1-1
        ACT/30,ARRAY(1,3),ATRIB(2).EQ.2,TST2;           LRS1-2
        ACT/31,ARRAY(1,4),ATRIB(2).EQ.3,TST3;           LRS1-3
        ACT/32,ARRAY(1,5),ATRIB(2).EQ.4,TST4;           LRS1-4
        ACT/33,ARRAY(1,6),ATRIB(2).EQ.5,TST5;           LRS1-5
        ACT/34,ARRAY(1,7),ATRIB(2).EQ.6,TST6;           LRS1-6
EVN1    EVENT,1;                                 CANCEL UNNEEDED BACKORDERS
        ACT;
;
;       COLLECT STATISTICS
;       ------------------
        ASSIGN,XX(62)=XX(62)+TNOW-ATRIB(1);
        ACT;
DAT1    COLCT,INT(1),SYS1 DOWN TIME,25/0/5;
        ACT,,,Q1;
;
; BASE MAINTENANCE ACTIVITY
; --------------------------
OLM1    ASSIGN,ATRIB(7)=TNOW;
OMQ1    QUEUE(21);                               AWAIT REPAIR
        ACT(5)/35,RLOGN(TMS1.STD1,3);            OLM1 REPAIR
TMS1    COLCT,INT(7),TMS BASE1,20/0/2;
TST1    GOON,1;                                  CHECK # SPARES IN STORE
        ACT,,ARRARY(10,1).EQ.1,CNT1;             1 LEVEL, BYPASS AS1 TEST
        ACT/36,FST1I,S1.GE.AH1,TSTI;             EX S1 TO ILM
        ACT;                                     ELSE
CNT1    ASSIGN,S1=S1+1;
        ACT,,,SU1;
;
;
;
; BASE 2 ACTIVITY
; ***************
;
; CREATE AUTHORIZED BASE SPARES
; -----------------------------
CS2       CREATE;
          ASSIGN,XX(5)=XX(5)+1;
          ACT,,XX(5).LT.AS2,CS2;
          ACT,,AS2.GT.0,CNT2;
          ACT;
          GOON;
          TERMINATE;
;
; CREATE OPERATING SYSTEMS. NUMBER OF SYSTEMS = NSYS2
; ---------------------------------------------------
ST2       CREATE;
          ASSIGN,XX(6)=XX(6)+1;
```

```
        ACT,,XX(6).LT.NSYS2,ST2;
        ACT,,NSYS2.GE.1,Q2;
        ACT,,,TERM;
;
; GENERATE FAILURES AT BASE
; ------------------------
;
Q2      ASSIGN,ATRIB(1)=TNOW,ATRIB(2)=2,ATRIB(3)=0,ATRIB(4)=0,
               ATRIB(5)=0,ATRIB(6)=0;
        ACT;
SYS2    QUEUE(32);
        ACT(20)/2,EXPON(MTBF2,3);             OP SYS U2
OPT2    COLCT,INT(1),AVG OP TIME B2,30/10/20;
        ACT;
;
; ALLOCATE FAILURE TO REPAIR LEVEL
; --------------------------------
;
        ASSIGN,ATRIB(1)=TNOW,XX(51)=XX(51)+1,1;  CNT # DEMANDS
        ACT/37,,P2DLM,DEP2;DLM REPAIR 2;
        ACT/38,,P2ILM,INT2;ILM REPAIR 2;
        ACT/39,,P2OLM,U2;OLM2 REPAIR;
;
DEP2    ASSIGN,ATRIB(5)=3,2;                  SET MAINTENANCE LEVEL FLAG
        ACT,FST2D,,DLM;                       TO DLM REPAIR QUEUE
        ACT,,S2.LT.1,BO2;                     NO BASE SPARE, BACKORDER
        ACT;                                  ELSE
        GOON;                                 HAVE BASE SPARE
        ACT,,,DU2;                            FIX DOWN SYSTEM
        ACT,,,DD;                             RESUP FROM ILM
;
INT2    ASSIGN,ATRIB(5)=2,2;                  SET MAINTENANCE LEVEL FLAG
        ACT,FST2I,,ILM;                       RI TO ILM REPAIR QUEUE
        ACT,,S2.LT.1,BO2;                     NO BASE SPARE, BACKORDER
        ACT;                                  ELSE
        GOON;                                 HAVE BASE SPARE
        ACT,,,DU2;                            FIX DOWN SYSTEM
        ACT,,,DI;                             RESUP FROM ILM
;
; BASE DEMAND ACTIVITY
; --------------------
U2      ASSIGN,ATRIB(5)=1,2;
        ACT,,,OLM2;                           FAILED RI TO OLM QUEUE
;
;       REPLACE FAILED RI WITH SPARE FROM BASE STORE
;       --------------------------------------------
        ACT,,S2.GE.1,DU2;                     FIX SYSTEM
        ACT;                                  ELSE
;
;       NO BASE SPARE, BACKORDER
;       ------------------------
```

```
BO2     ASSIGN,ATRIB(3)=1,XX(57)=XX(57)+1,2; SET BO FLAG & CNT BO'S
        ACT/40,,,DU2;# BO BASE 2            SUBMIT BO AT BASE
        ACT,,SI.GE.1,PDI;
        ACT,,SD.GE.1,DD;
;
;       LATERAL RESUPPLY OPTION
;       -----------------------
        ACT/41,,LRS.EQ.1,LRS;         U2-TRY LRS
        ACT;                          NO SPARE AT ILM, DLM OR OTHER BASES
        GOON,2;                       SEND BO TO BOTH ILM & DLM & WAIT
        ACT,,,PDI;
        ACT,,,DD;
;
;       BASE STORE
;       ----------
DU2     QUEUE(2),,,,SND2;                   PROCESS DEMAND
SU2     QUEUE(12),,,,SND2;                  BASE2 STORE
SND2    SELECT,ASM,,,DU2,SU2;               ASSEMBLE ORDER
        ACT;
;
;       DECREMENT SPARES
;       ----------------
        ASSIGN,S2=S2-1,1;
        ACT,,ATRIB(6).LT.0,LRR2;            LATERAL RESUPPLY REQUEST?
        ACT,,ATRIB(3).EQ.1,EVN2;            BO REQUEST?
        ACT,,,DAT2;                         ROUTINE DEMAND
LRR2    GOON,1;                             SHIP TO REQUESTING BASE
        ACT/42,ARRAY(2,2),ATRIB(2).EQ.1,TST1;      # LRS2-1
        ACT,ARRAY(2,3),ATRIB(2).EQ.2,TST2;         # LRS2-2
        ACT/44,ARRAY(2,4),ATRIB(2).EQ.3,TST3;      # LRS2-3
        ACT/45,ARRAY(2,5),ATRIB(2).EQ.4,TST4;      # LRS2-4
        ACT/46,ARRAY(2,6),ATRIB(2).EQ.5,TST5;      # LRS2-5
        ACT/47,ARRAY(2,7),ATRIB(2).EQ.6,TST6;      # LRS2-6
EVN2    EVENT,1;                            CANCEL UNNEEDED BACKORDERS
        ACT;
;
;       COLLECT STATISTICS
;       ------------------
        ASSIGN,XX(63)=XX(63)+TNOW-ATRIB(1);
        ACT;
DAT2    COLCT,INT(1),SYS2 DOWN TIME,25/0/5;
        ACT,,,Q2;
;
; BASE MAINTENANCE ACTIVITY
; -------------------------
OLM2    ASSIGN,ATRIB(7)=TNOW;
OMQ2    QUEUE(22);                          AWAIT REPAIR
        ACT(5)/48,RLOGN(TMS2,STD2,5);       OLM2 REPAIR
TMS2    COLCT,INT(7),TMS BASE2;    25/0/2;  HISTOGRAM DISABLED
TST2    GOON,1;                             CHECK # SPARES IN STORE
        ACT,,ARRARY(10,1).EQ.1,CNT2;        1 LEVEL, BYPASS AS2 TEST
```

```
      ACT/49,FST2I,S2.GE.AH2,TSTI;        EX S2 TO ILM
      ACT;                                ELSE
CNT2  ASSIGN,S2=S2+1;
      ACT,,,SU2;
;
;
;
; BASE 3 ACTIVITY
; ***************
;
; CREATE AUTHORIZED BASE SPARES
; ----------------------------
CS3     CREATE;
        ASSIGN,XX(7)=XX(7)+1;
        ACT,,XX(7).LT.AS3,CS3;
        ACT,,AS3.GT.0,CNT3;
        ACT;
        GOON;
        TERMINATE;
;
; CREATE OPERATING SYSTEMS. NUMBER OF SYSTEMS = NSYS3
; -------------------------------------------------
ST3     CREATE;
        ASSIGN,XX(8)=XX(8)+1;
        ACT,,XX(8).LT.NSYS3,ST3;
        ACT,,NSYS3.GE.1,Q3;
        ACT,,,TERM;
;
; GENERATE FAILURES AT BASE
; ------------------------
;
Q3      ASSIGN,ATRIB(1)=TNOW,ATRIB(2)=3,ATRIB(3)=0,ATRIB(4)=0,
               ATRIB(5)=0,ATRIB(6)=0;
        ACT;
SYS3    QUEUE(33);
        ACT(20)/3,EXPON(MTBF3,3);         OP SYS U3
        ACT;
;
; ALLOCATE FAILURE TO REPAIR LEVEL
; -------------------------------
;
        ASSIGN,ATRIB(1)=TNOW,XX(52)=XX(52)+1,1;   CNT # DEMANDS
        ACT/50,,P3DLM,DEP3;DLM REPAIR 3;
        ACT/51,,P3ILM,INT3;ILM REPAIR 3;
        ACT/52,,P3OLM,U3;OLM3 REPAIR;
;
DEP3    ASSIGN,ATRIB(5)=3,2;              SET MAINTENANCE LEVEL FLAG
        ACT,FST3D,,DLM;                   TO DLM REPAIR QUEUE
        ACT,,S3.LT.1,BO3;                 NO BASE SPARE, BACKORDER
        ACT;                              ELSE
        GOON;                             HAVE BASE SPARE
```

```
              ACT,,,DU3;                                FIX DOWN SYSTEM
              ACT,,,DD;                                 RESUP FROM ILM
;
INT3          ASSIGN,ATRIB(5)=2,2;                      SET MAINTENANCE LEVEL FLAG
              ACT,FST3I,,ILM;                           RI TO ILM REPAIR QUEUE
              ACT,,S3.LT.1,BO3;                         NO BASE SPARE, BACKORDER
              ACT;                                      ELSE
              GOON;                                     HAVE BASE SPARE
              ACT,,,DU3;                                FIX DOWN SYSTEM
              ACT,,,DI;                                 RESUP FROM ILM
;
; BASE DEMAND ACTIVITY
; --------------------
U3            ASSIGN,ATRIB(5)=1,2;
              ACT,,,OLM3;                               FAILED RI TO OLM QUEUE
;
;             REPLACE FAILED RI WITH SPARE FROM BASE STORE
;             --------------------------------------------
              ACT,,S3.GE.1,DU3;                         FIX SYSTEM
              ACT;                                      ELSE
;
;             NO BASE SPARE, BACKORDER
;             ------------------------
BO3           ASSIGN,ATRIB(3)=1,XX(58)=XX(58)+1,2;      SET BO FLAG & CNT BACKORDERS
              ACT/53,,,DU3;# BO BASE 3                  SUBMIT BO AT BASE
              ACT,,SI.GE.1,PDI;
              ACT,,SD.GE.1,DD;
;
;             LATERAL RESUPPLY OPTION
;             -----------------------
              ACT/54,,LRS.EQ.1,LRS;             U3-TRY LRS
              ACT;                              NO SPARE AT ILM, DLM OR OTHER BASES
              GOON,2;                           SEND BO TO BOTH ILM & DLM & WAIT
              ACT,,,PDI;
              ACT,,,DD;
;
;             BASE STORE
;             ----------
DU3           QUEUE(3),,,,SND3;                         PROCESS DEMAND
SU3           QUEUE(13),,,,SND3;                        BASE3 STORE
SND3          SELECT,ASM,,,DU3,SU3;                     ASSEMBLE ORDER
              ACT;
;
;             DECREMENT SPARES
;             ----------------
              ASSIGN,S3=S3-1,1;
              ACT,,ATRIB(6).LT.0,LRR3;                  LATERAL RESUPPLY REQUEST?
              ACT,,ATRIB(3).EQ.1,EVN3;                  BO REQUEST?
              ACT,,,DAT3;                               ROUTINE DEMAND
LRR3          GOON,1;                                   SHIP TO REQUESTING BASE
              ACT/55,ARRAY(3,2),ATRIB(2).EQ.1,TST1;         # LRS3-1
```

```
        ACT/56,ARRAY(3,3),ATRIB(2).EQ.2,TST2;       # LRS3-2
        ACT,ARRAY(3,4),ATRIB(2).EQ.3,TST3;          # LRS3-3
        ACT/58,ARRAY(3,5),ATRIB(2).EQ.4,TST4;       # LRS3-4
        ACT/59,ARRAY(3,6),ATRIB(2).EQ.5,TST5;       # LRS3-5
        ACT/60,ARRAY(3,7),ATRIB(2).EQ.6,TST6;       # LRS3-6
EVN3    EVENT,1;                                 CANCEL UNNEEDED BACKORDERS
        ACT;
;
;       COLLECT STATISTICS
;       ------------------
        ASSIGN,XX(64)=XX(64)+TNOW-ATRIB(1);      TIME AWAITING BO'S
        ACT;
DAT3    COLCT,INT(1),SYS3 DOWN TIME,25/0/5;
        ACT,,,Q3;
;
; BASE MAINTENANCE ACTIVITY
; -------------------------
OLM3    ASSIGN,ATRIB(7)=TNOW;
        QUEUE(23);                               AWAIT REPAIR
        ACT(5)/61,RLOGN(TMS3,STD3,6);            OLM3 REPAIR
TMS3    COLCT,INT(7),TMS BASE3;     25/0/2;      HISTOGRAM DISABLED
TST3    GOON,1;                                  CHECK # SPARES IN STORE
        ACT,,ARRARY(10,1).EQ.1,CNT3;             1 LEVEL, BYPASS AS3 TEST
        ACT/62,FST3I,S3.GE.AH3,TSTI;             EX S3 TO ILM
        ACT;                                     ELSE
CNT3    ASSIGN,S3=S3+1;
        ACT,,,SU3;
;
;
; BASE 4 ACTIVITY
; ***************
;
; CREATE AUTHORIZED BASE SPARES
; -----------------------------
CS4      CREATE;
         ASSIGN,XX(9)=XX(9)+1;
         ACT,,XX(9).LT.AS4,CS4;
         ACT,,AS4.GT.0,CNT4;
         ACT;
         GOON;
         TERMINATE;
;
; CREATE OPERATING SYSTEMS. NUMBER OF SYSTEMS = NSYS4
; --------------------------------------------------
ST4      CREATE;
         ASSIGN,XX(10)=XX(10)+1;
         ACT,,XX(10).LT.NSYS4,ST4;
         ACT,,NSYS4.GE.1,Q4;
         ACT,,,TERM;
;
; GENERATE FAILURES AT BASE
```

```
; -------------------------
;
Q4      ASSIGN,ATRIB(1)=TNOW,ATRIB(2)=4,ATRIB(3)=0,ATRIB(4)=0,
               ATRIB(5)=0,ATRIB(6)=0;
        ACT;
SYS4    QUEUE(34);
        ACT(20)/4,EXPON(MTBF4,7);              OP SYS U4
OPT4    COLCT,INT(1),AVG OP TIME B4;     ,30/10/20;   HISTOGRAM DISABLED
        ACT;
;
; ALLOCATE FAILURE TO REPAIR LEVEL
; -------------------------------
;
        ASSIGN,ATRIB(1)=TNOW,XX(53)=XX(53)+1,1;   CNT # DEMANDS
        ACT/63,,P4DLM,DEP4;DLM REPAIR 4;
        ACT/64,,P4ILM,INT4;ILM REPAIR 4;
        ACT/65,,P4OLM,U4;OLM4 REPAIR;
;
DEP4    ASSIGN,ATRIB(5)=3,2;                   SET MAINTENANCE LEVEL FLAG
        ACT,FST4D,,DLM;                        TO DLM REPAIR QUEUE
        ACT,,S4.LT.1,BO4;                      NO BASE SPARE, BACKORDER
        ACT;                                   ELSE
        GOON;                                  HAVE BASE SPARE
        ACT,,,DU4;                             FIX DOWN SYSTEM
        ACT,,,DD;                              RESUP FROM ILM
;
INT4    ASSIGN,ATRIB(5)=2,2;                   SET MAINTENANCE LEVEL FLAG
        ACT,FST4I,,ILM;                        RI TO ILM REPAIR QUEUE
        ACT,,S4.LT.1,BO4;                      NO BASE SPARE, BACKORDER
        ACT;                                   ELSE
        GOON;                                  HAVE BASE SPARE
        ACT,,,DU4;                             FIX DOWN SYSTEM
        ACT,,,DI;                              RESUP FROM ILM
;
; BASE DEMAND ACTIVITY
; --------------------
U4     ASSIGN,ATRIB(5)=1,2;
       ACT,,,OLM4;                             FAILED RI TO OLM QUEUE
;
;      REPLACE FAILED RI WITH SPARE FROM BASE STORE
;      --------------------------------------------
       ACT,,S4.GE.1,DU4;                       FIX SYSTEM
       ACT;                                    ELSE
;
;      NO BASE SPARE, BACKORDER
;      -------------------------
BO4    ASSIGN,ATRIB(3)=1,XX(59)=XX(59)+1,2;    SET BO FLAG & CNT BO'S
       ACT/66,,,DU4;# BO BASE 4                SUBMIT BO AT BASE
       ACT,,SI.GE.1,PDI;
       ACT,,SD.GE.1,DD;
;
```

```
;       LATERAL RESUPPLY OPTION
;       -----------------------
        ACT/67,,LRS.EQ.1,LRS;         U4-TRY LRS
        ACT;                          NO SPARE AT ILM, DLM OR OTHER BASES
        GOON,2;                       SEND BO TO BOTH ILM & DLM & WAIT
        ACT,,,PDI;
        ACT,,,DD;
;
;       BASE STORE
;       ----------
DU4     QUEUE(4),,,,SND4;                     PROCESS DEMAND
SU4     QUEUE(14),,,,SND4;                    BASE4 STORE
SND4    SELECT,ASM,,,DU4,SU4;                 ASSEMBLE ORDER
        ACT;
;
;       DECREMENT SPARES
;       ----------------
        ASSIGN,S4=S4-1,1;
        ACT,,ATRIB(6).LT.0,LRR4;              LATERAL RESUPPLY REQUEST?
        ACT,,ATRIB(3).EQ.1,EVN4;              BO REQUEST?
        ACT,,,DAT4;                           ROUTINE DEMAND
LRR4    GOON,1;                               SHIP TO REQUESTING BASE
        ACT/68,ARRAY(4,2),ATRIB(2).EQ.1,TST1;      # LRS4-1
        ACT/69,ARRAY(4,3),ATRIB(2).EQ.2,TST2;      # LRS4-2
        ACT/70,ARRAY(4,4),ATRIB(2).EQ.3,TST3;      # LRS4-3
        ACT,ARRAY(4,5),ATRIB(2).EQ.4,TST4;         # LRS4-4
        ACT/72,ARRAY(4,6),ATRIB(2).EQ.5,TST5;      # LRS4-5
        ACT/73,ARRAY(4,7),ATRIB(2).EQ.6,TST6;      # LRS4-6
EVN4    EVENT,1;                              CANCEL UNNEEDED BACKORDERS
        ACT;
;
;       COLLECT STATISTICS
;       ------------------
        ASSIGN,XX(65)=XX(65)+TNOW-ATRIB(1);
        ACT;
DAT4    COLCT,INT(1),SYS4 DOWN TIME,25/0/5;
        ACT,,,Q4;
;
; BASE MAINTENANCE ACTIVITY
; -------------------------
OLM4    ASSIGN,ATRIB(7)=TNOW;
OMQ4    QUEUE(24);                            AWAIT REPAIR
        ACT(5)/74,RLOGN(TMS4,STD4,9);         OLM4 REPAIR
TMS4    COLCT,INT(7),TMS BASE4;    ,20/0/2;   HISTOGRAM DISABLED
TST4    GOON,1;                               CHECK # SPARES IN STORE
        ACT,,ARRARY(10,1).EQ.1,CNT4;          1 LEVEL, BYPASS AS4 TEST
        ACT/75,FST4I,S4.GE.AH4,TSTI;          EX S4 TO ILM
        ACT;                                  ELSE
CNT4    ASSIGN,S4=S4+1;
        ACT,,,SU4;
;
```

```
;
; BASE 5 ACTIVITY
; ***************
;
; CREATE AUTHORIZED BASE SPARES
; ----------------------------
CS5       CREATE;
          ASSIGN,XX(11)=XX(11)+1;
          ACT,,XX(11).LT.AS5,CS5;
          ACT,,AS5.GT.0,CNT5;
          ACT;
          GOON;
          TERMINATE;
;
; CREATE OPERATING SYSTEMS. NUMBER OF SYSTEMS = NSYS2
; ------------------------------------------------
ST5       CREATE;
          ASSIGN,XX(12)=XX(12)+1;
          ACT,,XX(12).LT.NSYS5,ST5;
          ACT,,NSYS5.GE.1,Q5;
          ACT,,,TERM;
;
; GENERATE FAILURES AT BASE
; ------------------------
;
Q5        ASSIGN,ATRIB(1)=TNOW,ATRIB(2)=5,ATRIB(3)=0,ATRIB(4)=0,
                  ATRIB(5)=0,ATRIB(6)=0;
          ACT;
SYS5      QUEUE(35);
          ACT(20)/5,EXPON(MTBF5,4);           OP SYS U5
OPT5     COLCT,INT(1),AVG OP TIME B5;     ,30/10/20   HISTOGRAM DISABLED
          ACT;
;
; ALLOCATE FAILURE TO REPAIR LEVEL
; -------------------------------
;
          ASSIGN,ATRIB(1)=TNOW,XX(54)=XX(54)+1,1;   CNT # DEMANDS
          ACT/76,,P5DLM,DEP5;DLM REPAIR 5;
          ACT/77,,P5ILM,INT5;ILM REPAIR 5;
          ACT/78,,P5OLM,U5;OLM2 REPAIR;
;
DEP5      ASSIGN,ATRIB(5)=3,2;                    SET MAINTENANCE LEVEL FLAG
          ACT,FST5D,,DLM;                         TO DLM REPAIR QUEUE
          ACT,,S5.LT.1,BO5;                       NO BASE SPARE, BACKORDER
          ACT;                                    ELSE
          GOON;                                   HAVE BASE SPARE
          ACT,,,DU5;                              FIX DOWN SYSTEM
          ACT,,,DD;                               RESUP FROM ILM
;
INT5      ASSIGN,ATRIB(5)=2,2;                    SET MAINTENANCE LEVEL FLAG
          ACT,FST5I,,ILM;                         RI TO ILM REPAIR QUEUE
```

```
          ACT,,S5.LT.1,BO5;                      NO BASE SPARE, BACKORDER
          ACT;                                   ELSE
          GOON;                                  HAVE BASE SPARE
          ACT,,,DU5;                             FIX DOWN SYSTEM
          ACT,,,DI;                              RESUP FROM ILM
;
; BASE DEMAND ACTIVITY
; --------------------
U5        ASSIGN,ATRIB(5)=1,2;
          ACT,,,OLM5;                            FAILED RI TO OLM QUEUE
;
;         REPLACE FAILED RI WITH SPARE FROM BASE STORE
;         ------------------------------------------
          ACT,,S5.GE.1,DU5;                      FIX SYSTEM
          ACT;                                   ELSE
;
;         NO BASE SPARE, BACKORDER
;         ------------------------
BO5       ASSIGN,ATRIB(3)=1,XX(60)=XX(60)+1,2;   SET BO FLAG & CNT BO'S
          ACT/79,,,DU5;# BO BASE 5               SUBMIT BO AT BASE
          ACT,,SI.GE.1,PDI;
          ACT,,SD.GE.1,DD;
;
;         LATERAL RESUPPLY OPTION
;         -----------------------
          ACT/80,,LRS.EQ.1,LRS;          U5-TRY LRS
          ACT;                           NO SPARE AT ILM, DLM OR OTHER BASES
          GOON,2;                        SEND BO TO BOTH ILM & DLM & WAIT
          ACT,,,PDI;
          ACT,,,DD;
;
;         BASE STORE
;         ----------
DU5       QUEUE(5),,,,SND5;                      PROCESS DEMAND
SU5       QUEUE(15),,,,SND5;                     BASE5 STORE
SND5      SELECT,ASM,,,DU5,SU5;                  ASSEMBLE ORDER
          ACT;
;
;         DECREMENT SPARES
;         ----------------
          ASSIGN,S5=S5-1,1;
          ACT,,ATRIB(6).LT.0,LRR5;               LATERAL RESUPPLY REQUEST?
          ACT,,ATRIB(3).EQ.1,EVN5;               BO REQUEST?
          ACT,,,DAT5;                            ROUTINE DEMAND
LRR5      GOON,1;                                SHIP TO REQUESTING BASE
          ACT/81,ARRAY(5,2),ATRIB(2).EQ.1,TST1;        # LRS5-1
          ACT/82,ARRAY(5,3),ATRIB(2).EQ.2,TST2;        # LRS5-2
          ACT/83,ARRAY(5,4),ATRIB(2).EQ.3,TST3;        # LRS5-3
          ACT/84,ARRAY(5,5),ATRIB(2).EQ.4,TST4;        # LRS5-4
          ACT,ARRAY(5,6),ATRIB(2).EQ.5,TST5;           # LRS5-5
          ACT/86,ARRAY(5,7),ATRIB(2).EQ.6,TST6;        # LRS5-6
```

```
EVN5    EVENT,1;                                  CANCEL UNNEEDED BACKORDERS
        ACT;
;
;       COLLECT STATISTICS
;       ------------------
        ASSIGN,XX(66)=XX(66)+TNOW-ATRIB(1);
        ACT;
DAT5    COLCT,INT(1),SYS5 DOWN TIME,25/0/5;
        ACT,,,Q5;
;
; BASE MAINTENANCE ACTIVITY
; ------------------------
OLM5    ASSIGN,ATRIB(7)=TNOW;
OMQ5    QUEUE(25);                                AWAIT REPAIR
        ACT(5)/87,RLOGN(TMS5,STD5,7);             OLM5 REPAIR
TMS5    COLCT,INT(7),TMS BASE5;    ,20/0/2;       HISTOGRAM DISABLED
TST5    GOON,1;                                   CHECK # SPARES IN STORE
        ACT,,ARRARY(10,1).EQ.1,CNT5;              1 LEVEL, BYPASS AS5 TEST
        ACT/88,FST5I,S5.GE.AH5,TSTI;              EX S5 TO ILM
        ACT;                                      ELSE
CNT5    ASSIGN,S5=S5+1;
        ACT,,,SU5;
;
;
;
;
; BASE 6 ACTIVITY
; ***************
;
; CREATE AUTHORIZED BASE SPARES
; ----------------------------
CS6     CREATE;
        ASSIGN,XX(13)=XX(13)+1;
        ACT,,XX(13).LT.AS6,CS6;
        ACT,,AS6.GT.0,CNT6;
        ACT;
        GOON;
        TERMINATE;
;
; CREATE OPERATING SYSTEMS. NUMBER OF SYSTEMS = NSYS6
; --------------------------------------------------
ST6     CREATE;
        ASSIGN,XX(14)=XX(14)+1;
        ACT,,XX(14).LT.NSYS6,ST6;
        ACT,,NSYS6.GE.1,Q6;
        ACT,,,TERM;
;
; GENERATE FAILURES AT BASE
; -------------------------
;
Q6      ASSIGN,ATRIB(1)=TNOW,ATRIB(2)=6,ATRIB(3)=0,ATRIB(4)=0,
```

```
                     ATRIB(5)=0,ATRIB(6)=0;
              ACT;
SYS6          QUEUE(36);
              ACT(20)/6,EXPON(MTBF6,9);          OP SYS U6
OPT6         COLCT,INT(1),AVG OP TIME B6;    ,30/10/20; HISTOGRAM DISABLED
              ACT;
;
; ALLOCATE FAILURE TO REPAIR LEVEL
; ------------------------------
;
              ASSIGN,ATRIB(1)=TNOW,XX(55)=XX(55)+1,1;   CNT # DEMANDS
              ACT,,P6DLM,DEP6;DLM REPAIR 6;
              ACT,,P6ILM,INT6;ILM REPAIR 6;
              ACT,,P6OLM,U6;OLM6 REPAIR;
;
DEP6          ASSIGN,ATRIB(5)=3,2;                SET MAINTENANCE LEVEL FLAG
              ACT,FST6D,,DLM;                     TO DLM REPAIR QUEUE
              ACT,,S6.LT.1,BO6;                   NO BASE SPARE, BACKORDER
              ACT;                                ELSE
              GOON;                               HAVE BASE SPARE
              ACT,,,DU6;                          FIX DOWN SYSTEM
              ACT,,,DD;                           RESUP FROM ILM
;
INT6          ASSIGN,ATRIB(5)=2,2;                SET MAINTENANCE LEVEL FLAG
              ACT,FST6I,,ILM;                     RI TO ILM REPAIR QUEUE
              ACT,,S6.LT.1,BO6;                   NO BASE SPARE, BACKORDER
              ACT;                                ELSE
              GOON;                               HAVE BASE SPARE
              ACT,,,DU6;                          FIX DOWN SYSTEM
              ACT,,,DI;                           RESUP FROM ILM
;
; BASE DEMAND ACTIVITY
; --------------------
U6           ASSIGN,ATRIB(5)=1,2;
             ACT,,,OLM6;                          FAILED RI TO OLM QUEUE
;
;            REPLACE FAILED RI WITH SPARE FROM BASE STORE
;            -------------------------------------------
             ACT,,S6.GE.1,DU6;                    FIX SYSTEM
             ACT;                                 ELSE
;
;            NO BASE SPARE, BACKORDER
;            ------------------------
BO6          ASSIGN,ATRIB(3)=1,XX(61)=XX(61)+1,2; SET BO FLAG & CNT BO'S
             ACT/89,,,DU6;# BO BASE 6             SUBMIT BO AT BASE
             ACT,,SI.GE.1,PDI;
             ACT,,SD.GE.1,DD;
;
;            LATERAL RESUPPLY OPTION
;            -----------------------
             ACT/90,,LRS.EQ.1,LRS;         U6-TRY LRS
```

```
        ACT;                                    NO SPARE AT ILM, DLM OR OTHER BASES
        GOON,2;                                 SEND BO TO BOTH ILM & DLM & WAIT
        ACT,,,PDI;
        ACT,,,DD;
;
;       BASE STORE
;       ----------
DU6     QUEUE(6),,,,SND6;                               PROCESS DEMAND
SU6     QUEUE(16),,,,SND6;                              BASE6 STORE
SND6    SELECT,ASM,,,DU6,SU6;                           ASSEMBLE ORDER
        ACT;
;
;       DECREMENT SPARES
;       ----------------
        ASSIGN,S6=S6-1,1;
        ACT,,ATRIB(6).LT.0,LRR6;                        LATERAL RESUPPLY REQUEST?
        ACT,,ATRIB(3).EQ.1,EVN6;                        BO REQUEST?
        ACT,,,DAT6;                                     ROUTINE DEMAND
LRR6    GOON,1;                                         SHIP TO REQUESTING BASE
        ACT/91,ARRAY(6,2),ATRIB(2).EQ.1,TST1;                 # LRS6-1
        ACT/92,ARRAY(6,3),ATRIB(2).EQ.2,TST2;                 # LRS6-2
        ACT/93,ARRAY(6,4),ATRIB(2).EQ.3,TST3;                 # LRS6-3
        ACT/94,ARRAY(6,5),ATRIB(2).EQ.4,TST4;                 # LRS6-4
        ACT/95,ARRAY(6,6),ATRIB(2).EQ.5,TST5;                 # LRS6-5
        ACT,ARRAY(6,7),ATRIB(2).EQ.6,TST6;                    # LRS6-6
EVN6    EVENT,1;                                        CANCEL UNNEEDED BACKORDERS
        ACT;
;
;       COLLECT STATISTICS
;       ------------------
        ASSIGN,XX(67)=XX(67)+TNOW-ATRIB(1);
        ACT;
DAT6    COLCT,INT(1),SYS6 DOWN TIME,25/0/5;
        ACT,,,Q6;
;
; BASE MAINTENANCE ACTIVITY
; -------------------------
OLM6    ASSIGN,ATRIB(7)=TNOW;
OMQ6    QUEUE(26);                                      AWAIT REPAIR
        ACT(5)/96,RLOGN(TMS6,STD6,7);                   OLM6 REPAIR
TMS6    COLCT,INT(7),TMS BASE6;    ,25/0/2;             HISTOGRAM DISABLED
TST6    GOON,1;                                         CHECK # SPARES IN STORE
        ACT,,ARRARY(10,1).EQ.1,CNT6;                    1 LEVEL, BYPASS AS6 TEST
        ACT/97,FST6I,S6.GE.AH6,TSTI;                    EX S6 TO ILM
        ACT;                                            ELSE
CNT6    ASSIGN,S6=S6+1;
        ACT,,,SU6;
;
;
; MONITOR STATEMENTS
; ------------------
```

```
; SPARES STATUS. FOR DIM, ILM & BASES 1-3. TNOW=0 TO 160
; -------------------------------------------------------
;MONTR,TRACE,0.,160.,NNQ(28),NNQ(8),NNQ(1),NNQ(2),NNQ(3),
;                    NNQ(29),NNQ(9),NNQ(11),NNQ(12),NNQ(13);
;
        END;
INIT,0,20000;
MONTR,CLEAR,10000.001; ADD .001 TO CLEAR TIME TO PREVENT TIMING PROBLEM
FIN;
```

APPENDIX C. MODEL SUBROUTINES

```
      PROGRAM MAIN
C     AMENDMENT DATE: 13 JUNE 90
C
C     DIRECT QUESTIONS TO 5028P
C
      DIMENSION NSET(30000)
      COMMON/SCOM1/ATRIB(100), DD(100), DDL(100), DTNOW, II, MFA,
     1MSTOP,NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(100),
     2SSL(100),TNEXT, TNOW, XX(100)
      COMMON QSET(30000)
      EQUIVALENCE (NSET(1),QSET(1))
C
C
C
      NNSET = 30000
      NCRDR=5
      NPRNT=6
      NTAPE=7
      CALL SLAM
      STOP
      END
C_____________________________________________________________________
      SUBROUTINE INTLC
C
C     INITIALIZES COUNTERS USED IN SUBROUTINES AND
C     SCHEDULES FIRST OCCURRENCE OF EVENT 2 (SUBROUTINE STATS)
C     AT TIME = SAMPLT
C
      REAL SAMPLT
      INTEGER ADIM
      PARAMETER (SAMPLT = 1000.0)
C
      PARAMETER (ADIM = 12)
      INTEGER BAKORD(6), DEMAND(6), CTR(6)
      REAL TIMBAK(6), A(ADIM)
      REAL TDMAND(6), TBO(6), TTIMBO(6), TAO(6), TSL(6), TBPDAY(6)
      REAL TAVBOT(6), TMSRT(6), CLEAR, END, TIME, TTWBO(6)
      COMMON/STATCO/BAKORD, TIMBAK, DEMAND, TDMAND, TBO, TTIMBO,
     &TAO, TSL, TBPDAY, TAVBOT, TMSRT, CTR, TTWBO
C
C     INITIALIZE COUNTERS AND ATRIB ARRAY TO ZERO
C
      DO 1000 I = 1, 6
         DEMAND(I) = 0
```

```
          BAKORD(I) = 0
          TIMBAK(I) = 0.0
          TDMAND(I) = 0.0
          TBO(I) = 0.0
          TTIMBO(I) = 0.0
          TAO(I) = 0.0
          TSL(I) = 0.0
          TBPDAY(I) = 0.0
          TAVBOT(I) = 0.0
          TMSRT(I) = 0.0
          CTR(I) = 0
          TTWBO(I) = 0.0
1000  CONTINUE
      DO 1001 I = 1, ADIM
        A(I) = 0.0
1001  CONTINUE
      CALL SCHDL(2, SAMPLT, A)
C
      RETURN
      END
C_____________________________________________________________________

      SUBROUTINE EVENT(EVT)
      INTEGER EVT
C
      GO TO (100, 200, 300) EVT
C
C**********************************************************************
C     EVENT CANBO CANCELS BACKORDERS FROM THE  INTERMEDIATE AND DEPOT
C     DEMAND QUEUES WHEN A BO IS SATISFIED
C
100   CALL CANBO
      RETURN
C
C**********************************************************************
C     EVENT STATS IS SCHEDULED TO COLLECT INTERMED STATS
C
200   CALL STATS
      RETURN
C
C**********************************************************************
C     LATSUP IS CALLED WHENEVER A BASE HAS A BACKORDER AND BOTH ILM
C     AND DLM HAVE NO SPARES.  LATERAL RESUPPLY FROM ANOTHER BASE IS
C     THEN ATTEMPTED.  DECISION RULE: SELECT CLOSEST (SHIPPING TIME)
C     BASE. IN CASES OF TIES, SELECT BASE WITH MOST SPARES.
C
300   CALL LATSUP
      RETURN
      END
C
C**********************************************************************
```

```
C_____________________________________________________________________
      SUBROUTINE CANBO
C
C     EVENT CANBO CANCELS BACKORDERS FROM THE  INTERMEDIATE AND DEPOT
C     DEMAND QUEUES WHEN A BO IS SATISFIED BY OLM OR ILM
C
C     SCOM1 IS THE ALMIGHTY COMMON BLOCK WITH ALL OF THE SLAM
C     VARIABLES --- THIS MUST BE EXACTLY AS GIVEN IN THE BOOK
C
      COMMON/SCOM1/ATRIB(100), DD(100), DDL(100), DTNOW, II, MFA,
     1MSTOP,NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(100),
     2SSL(100),TNEXT, TNOW, XX(100)
C
      INTEGER ADIM, INTFLE, DEPFLE
      PARAMETER (ADIM = 15)
      PARAMETER (INTFLE  = 8)
      PARAMETER (DEPFLE = 28)
      REAL A(ADIM)
      INTEGER I
      PARAMETER (TOL = 1.0E-8)
C
1212  FORMAT(6(F9.2, '  '))
C
      DO 1000 I = 1, NNQ(INTFLE)
         CALL COPY(I, INTFLE, A)
         IF ( ABS(A(1)-ATRIB(1)).LT.TOL
     &   .AND.ABS(A(2)-ATRIB(2)).LT.TOL) THEN
         CALL RMOVE (I, INTFLE, A)
         GOTO 999
         END IF
C
1000  CONTINUE
999   CONTINUE
C
      DO 2000 I = 1, NNQ(DEPFLE)
         CALL COPY(I, DEPFLE, A)
         IF (ABS(A(1)-ATRIB(1)).LT.TOL
     &   .AND.ABS(A(2)-ATRIB(2)).LT.TOL) THEN
         CALL RMOVE (I, DEPFLE, A)
         GOTO 1999
         END IF
C
2000  CONTINUE
1999  CONTINUE
      RETURN
      END
C_____________________________________________________________________
C_____________________________________________________________________
C
      SUBROUTINE STATS
C
```

```
C      1.  COLLECTS SOME STATISTICS ABOUT BACKORDERS
C      2.  WRITES THESE AND OTHER STATISTICS TO FILE NPRNT
C      3.  RESCHEDULES ITSELF
C      ***************************************************
C
C      DEMAND = # DEMANDS DURING SAMPLE TIME (SAMLT)
C      BAKORD = # BACKORDERS DURING SAMPLE TIME
C      TIMBAK = TOTAL TIME BACKOREDERS ARE OUTSTANDING DURING SAMPLT
C      SL =SERVICE LEVEL= # DEMANDS FILLED WITHOUT A SHERBROOKE BACKORDR
C      BPDAY = BACKORDERS PER 100 DAYS
C      AVGBOT = AVERAGE BACKORDER TIME DELAY
C      MSRT = MEAN SUPPLY RESPONSE TIME
C      UNITN = BASE NUMBER
C      AO = OPERATIONAL AVAILABILITY
C      DTIME = SYSTEM DOWN TIME
C      NSYS(I) = NUMBER OF SYSTEMS AT BASE I
C      TDMAND = TOTAL DEMAND AFTER CLEARING SLAM II STAT ARRAYS
C      TBO = TOTAL BACKORDERS AFTER CLEARING SLAM II STAT ARRAYS
C      TTIMBO = TIME BO'S ARE OUTSTANDING  AFTER CLEARING STAT ARRAYS
C      TAO = AO AFTER CLEARING STAT ARRAYS
C      TSTD = STANDARD DEVIATION AFTER CLEARING ARRAYS
C      TWBO = TIME WEIGHTED BACKORDERS PER DAY
C
C      REQUIRES THAT FAILURE SERVICE ACTIVITIES ARE NUMBERED
C          OFFSET + 1, OFFSET + 2, ...., OFFSET + 6
C      OFSETD = OFFSET FOR DEMAND COUNTERS
C      OFSETB = OFFSET FOR BACKORDER COUNTERS
C      OFSETT = OFFSET FOR BACKORDER DURATION COUNTERS
C
C      REQUIRES THAT DEMAND COUNTERS ARE OFFSET BY OFSETD
C
C      REQUIRES STATCO
C
       COMMON/SCOM1/ATRIB(100), DD(100), DDL(100), DTNOW, II, MFA,
      1MSTOP,NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(100),
      2SSL(100),TNEXT, TNOW, XX(100)
C
       REAL SAMPLT
       INTEGER ADIM
       PARAMETER (SAMPLT = 1000.0)
       PARAMETER (ADIM = 15)
       REAL A(ADIM)
       INTEGER BAKORD(6), DEMAND(6), CTR(6)
       REAL TIMBAK(6)
       REAL TDMAND(6), TBO(6), TTIMBO(6), TAO(6), TSL(6), TBPDAY(6)
       REAL TAVBOT(6), TMSRT(6), CLEAR, END, TIME, TWBO(6), TTWBO(6)
       COMMON/STATCO/BAKORD, TIMBAK, DEMAND, CTR, TDMAND, TBO, TTIMBO,
      &TAO, TSL, TBPDAY, TAVBOT, TMSRT, TTWBO
C
       INTEGER OFFSET, NSYS(6), OFSETD, OFSETB, OFSETT
       PARAMETER (OFFSET = 0)
```

```
      PARAMETER (OFSETD = 49)
      PARAMETER (OFSETB = 55)
      PARAMETER (OFSETT = 61)
      INTEGER I, UNITN
      REAL BPDAY(6), AVGBOT(6), AO(6), STDUT(6), SL(6), MSRT(6)
C
C     CALLED EVERY SAMPLT TIME UNITS TO COLLECT STATISTICS
C
C     IMPORT DATA FROM NETWORK
C
      CLEAR = REAL(GETARY(10,4))
      END = REAL(GETARY(10,5))
      UNITN = NINT(GETARY(10, 2))
C
C     CALCULATE STATS FOR SAMPLE PERIOD = SAMPLT
C
      DO 1001 I = 1, UNITN
          DEMAND(I)  = XX(I+OFSETD)
          BAKORD(I)  = XX(I+OFSETB)
          TIMBAK(I)  = XX(I+OFSETT)
          SL(I)  = REAL((DEMAND(I)-BAKORD(I))*100)/DEMAND(I)
          BPDAY(I)  = REAL((BAKORD(I))/SAMPLT)*100
          IF (BAKORD(I).GT.0) THEN
             AVGBOT(I)  = TIMBAK(I)/REAL(BAKORD(I))
             MSRT(I)  = REAL(TIMBAK(I)/DEMAND(I))
          ENDIF
          TWBO(I)  =  (BPDAY(I)/100)*AVGBOT(I)
          NSYS(I)  = NINT(GETARY(I,1))
          AO(I)  =  (AAAVG(I + OFFSET))*100/NSYS(I)
          STDUT(I)  =  (AASTD(I + OFFSET)*100)/NSYS(I)
          XX(I+OFSETD)  = 0
          XX(I+OFSETB)  = 0
          XX(I+OFSETT)  = 0.0
1001  CONTINUE
C
C     CALCULATE STATS FOR PERIOD CLEAR - END
C
      DO 1002 I = 1, UNITN
          IF (TNOW.GE.CLEAR) THEN
            CTR(I)  = CTR(I)+1
            TDMAND(I)  = TDMAND(I)+DEMAND(I)
            TBO(I)  = TBO(I)+BAKORD(I)
            TTIMBO(I)  = TTIMBO(I)+TIMBAK(I)
            TAO(I)  = TAO(I)+AO(I)
            TTWBO(I)  = TTWBO(I)+TWBO(I)
          ENDIF

          IF (TNOW.GE.END) THEN
            TIME = REAL(TNOW-CLEAR)
            TSL(I)  = REAL((TDMAND(I)-TBO(I))*100)/TDMAND(I)
            TBPDAY(I)  = REAL((TBO(I))/TIME)*100
```

```
          TAVBOT(I) = TTIMBO(I)/REAL(TBO(I))
          TBO(I) = REAL((TBO(I))/TIME)*100
          TMSRT(I) = REAL(TTIMBO(I)/TDMAND(I))
          TAO(I) = TAO(I)/CTR(I)
          TTWBO(I) = TTWBO(I)/CTR(I)
        ENDIF
1002   CONTINUE
C
C
C      * * * * * * * * * * * * * * * * * * * * * * * * *
      WRITE(NPRNT, 3) 'SYSTEM STATISTICS FOR  SAMPLE PERIOD ENDING AT TI
     &ME ', TNOW
      WRITE(NPRNT, *)
      WRITE(NPRNT,*) 'BASE  SL%   B ORDERS AVG BO TIME TWBO',
     &    '       MSRT         OPERATIONAL '
      WRITE(NPRNT,*) '              /100 DAYS IN DAYS     BO-DAYS/DAY IN DA
     &YS      AVAIL% STD DEV%'
      WRITE(NPRNT, *)
      DO 1003 I = 1, UNITN
      WRITE(NPRNT,1) I,SL(I),BPDAY(I),AVGBOT(I),TWBO(I),MSRT(I),AO(I),
     &  STDUT(I)
1003  CONTINUE
1     FORMAT(2X,I2,1X,F5.1,2X,E9.3,1X,E9.3,3X,E9.3,3X,E9.3,3X,
     &F5.1,1X,F5.1)
3     FORMAT(A54,F9.2)
      WRITE(NPRNT, *)
      WRITE(NPRNT, *)
C
C
      IF (TNOW.GE.END) THEN
      WRITE(NPRNT, *) '**************************************************
     &**********************'
      WRITE(NPRNT, 4) 'SYSTEM STATS FROM TIME CLEAR TO END. SAMPLE PERIO
     &D (DAYS) =', TIME
      WRITE(NPRNT, *)
      WRITE(NPRNT,*) 'BASE  SL%   B ORDERS  AVG BO TIME   TWBO',
     &    '      MSRT          OPERATIONAL '
      WRITE(NPRNT,*) '              /100 DAYS  IN DAYS      BO-DAYS/DAY IN
     &DAYS       AVAIL% '
      WRITE(NPRNT, *)
      DO 1033 I = 1, UNITN
      WRITE(NPRNT,2) I,TSL(I),TBPDAY(I),TAVBOT(I),TTWBO(I),TMSRT(I),
     & TAO(I)
1033  CONTINUE
4     FORMAT(A60,F9.2)
2     FORMAT(2X,I2,1X,F5.1,2X,E9.3,2X,E9.3,4X,E9.3,3X,E9.3,5X,F5.1)
      WRITE(NPRNT, *) '**************************************************
     &**********************'
      WRITE(NPRNT, *)
      WRITE(NPRNT, *)
      ENDIF
```

```
C
      DO 1004 I = 1, ADIM
        A(I) = 0.0
1004  CONTINUE
      CALL SCHDL(2, SAMPLT, A)
C
      RETURN
      END
C
C_______________________________________________________________________
      SUBROUTINE LATSUP
C
C     LATSUP IS CALLED WHENEVER A BASE HAS A BACKORDER AND BOTH ILM
C     AND DLM HAVE NO SPARES.  LATERAL RESUPPLY FROM ANOTHER BASE IS
C     THEN ATTEMPTED.  DECISION RULE: SELECT CLOSEST (SHIPPING TIME)
C     BASE. IN CASES OF TIES, SELECT BASE WITH MOST SPARES.
C
C     IF LATERAL RESUPPLY IS POSSIBLE
C     -------------------------------
C     THIS IS ACCOMPLISHED BY INSERTING A DEMAND AT THE CHOSEN
C     UNLUCKY (DONOR) BASE FOR A PART TO BE SENT TO THE DEMANDING,
C     GREEDY, UNPREPARED BASE.  A(6) OF THE BACKORDER DEMAND
C     FILED AT THE DONOR IS SET TO -1.0 IF A DONOR HAS A SPARE.
C     ALL OTHER ATTRIBUTES ARE THOSE OF THE REQUESTOR'S
C     BASE, WHICH ARE FOUND AS THE ATTRIBUTES OF THE TRIGGERING ENTITY.
C     THIS ALSO TRIGGERS A DEMAND AT THE INTERMEDIATE NODE TO REPLACE
C     ITS GENEROUSLY GIVEN RESOURCE, THIS DEMAND IS ROUTINE, NOT A BO.
C     THE ATTRIBUTES OF THIS RESUPPLY DEMAND (TO ILM) ARE THOSE OF THE
C     DONOR, WITH ALL ATRIBS = 0 EXCEPT A(2) = # OF DONOR BASE.
C
C     IF LATERAL RESUPPLY IS NOT POSSIBLE
C     -----------------------------------
C     IF NO LATERAL RESUPPLY OCCURS, A BACKORDER DEMAND FOR THE
C     REQUESTING BASE IN THE ILM AND DLM QUEUE.  THESE HAVE A(1) - A(5)
C     EQUAL TO THE TRIGGERING
C     ENTITY, AND A(6) = 1.0 (NO LATSUP AVAILABLE).
C
C     REQUIRED : CALLED UPON OCCURRENCE OF A BACKORDER WITH NO ILM
C                OR DLM SPARE AVAILABLE.
C                ATRIB(1) = TIME DEMAND WAS MADE
C                ATRIB(2) = BASE FROM WHICH DEMAND WAS MADE
C                SPARES QUEUES FOR BASES ARE NUMBERED
C                         OFFST1+ 1, ..., OFFST1 + 6
C                DEMAND QUEUES FOR BASE SPARES ARE NUMBERED
C                         OFFST2+ 1, ..., OFFST2 + 6
C
      COMMON/SCOM1/ATRIB(100), DD(100), DDL(100), DTNOW, II, MFA,
     1MSTOP,NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(100),
     2SSL(100),TNEXT, TNOW, XX(100)
C
      INTEGER ADIM, OFFST1, OFFST2
```

```
      REAL TOL
      PARAMETER (TOL = 1.0E-8)
C     OFFSET1 (2) IS OFFSET FOR SPARES(DEMANDS) OF THE BASES
      PARAMETER (OFFST1 = 10)
      PARAMETER (OFFST2 = 0)
      PARAMETER (ADIM = 15)
      INTEGER NUMATR, INTFLE, DEPFLE, UNITN, J
      PARAMETER (INTFLE  = 8)
      PARAMETER (DEPFLE = 28)
      INTEGER REQSTR, CLOSE(6), SENDER, COUNT
      REAL MINDIS, DIS(6), A(ADIM)
C
      UNITN = NINT(GETARY(10, 2))
C
      REQSTR = NINT(ATRIB(2))
      J = REQSTR+1
      SENDER = 0
      DO 1001 I = 1, UNITN
1001     DIS(I) = GETARY(I, J)
C
      MINDIS = 1.0E7
      DO 1002 I = 1, UNITN
         IF (I.NE.REQSTR.AND.DIS(I).LT.MINDIS.AND.
     &        NNQ(I + OFFST1).GT.0) MINDIS = DIS(I)
1002  CONTINUE
C
      COUNT = 0
      DO 1003 I = 1, UNITN
         IF (I.NE.REQSTR.AND.ABS(DIS(I)-MINDIS).LT.TOL.AND.
     &        NNQ(I + OFFST1).GT.0) THEN
            CLOSE(I) = 1
            COUNT = COUNT + 1
            SENDER = I
         ELSE
            CLOSE(I) = 0
         ENDIF
1003  CONTINUE
C
      IF (COUNT.GT.1) THEN
C        SECONDARY RULE APPLIED: WHO HAS THE MOST TO GIVE?
         COUNT = 0
         SENDER = 0
         DO 1005 I = 1, UNITN
            IF (CLOSE(I).EQ.1.AND.NNQ(I + OFFST1).GT.COUNT) THEN
               SENDER = I
               COUNT = NNQ(I + OFFST1)
            ENDIF
1005     CONTINUE
      ENDIF
C
C     AT THIS POINT, SENDER IS UNIQUE.  IF SENDER IS NOT ZERO, WE
```

```
C     WILL HAVE LATERAL RESUPPLY.  IF SENDER IS ZERO, WE ARE
C     STUMPED.
C
      IF (SENDER.EQ.0) THEN
         DO 1006 I = 1, ADIM
1006        A(I) = ATRIB(I)
         A(6) = 1.0
         CALL FILEM(INTFLE, A)
         CALL FILEM(DEPFLE, A)
         RETURN
      ELSE
         DO 1007 I = 1, ADIM
1007        A(I) = ATRIB(I)
C     FILE A DEMAND AT THE SENDER'S DEMAND QUEUE
C     THIS DEMAND HAS THE SAME ATRIB VALUES AS THE BACKORDER WHICH
C     CAUSES THE LATSUP EVENT TO OCCUR, WITH THE EXCEPTION OF A(6)
C
         A(6) = -1.0
         CALL FILEM(SENDER + OFFST2, A)
C
         DO 1008 I = 1, ADIM
1008        A(I) = 0.0
         A(2) = REAL(SENDER)
         CALL FILEM(INTFLE, A)
      ENDIF
      RETURN
      END
```

APPENDIX D. SAMPLE SUMMARY REPORT FOR THREE-ECHELON, SIX-BASE SIMULATION WITH LATERAL RESUPPLY

```
**********************************************************************
*                                                                    *
*                                                                    *
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*                    *   SLAM II VERSION 4.03  *                     *
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*                                                                    *
**********************************************************************
1
1                                           **INTERMEDIATE RESULTS**


 SYSTEM STATISTICS FOR  SAMPLE PERIOD ENDING AT TIME   1000.00

BASE  SL%   B ORDERS AVG BO TIME TWBO         MSRT       OPERATIONAL
            /100 DAYS IN DAYS    BO-DAYS/DAY  IN DAYS    AVAIL% STD DEV%

  1 100.0  0.000E+00 0.000E+00   0.000E+00   0.000E+00   100.0   0.0
  2 100.0  0.000E+00 0.000E+00   0.000E+00   0.000E+00   100.0   0.0
  3 100.0  0.000E+00 0.000E+00   0.000E+00   0.000E+00   100.0   0.0
  4  92.7  0.900E+00 0.999E+00   0.899E-02   0.731E-01    99.9   0.6
  5 100.0  0.000E+00 0.000E+00   0.000E+00   0.000E+00   100.0   0.0
  6 100.0  0.000E+00 0.000E+00   0.000E+00   0.000E+00   100.0   0.0
```

SYSTEM STATISTICS FOR SAMPLE PERIOD ENDING AT TIME 2000.00

BASE	SL%	B ORDERS /100 DAYS	AVG BO TIME IN DAYS	TWBO BO-DAYS/DAY	MSRT IN DAYS	OPERATIONAL AVAIL%	STD DEV%
1	97.3	0.200E+00	0.100E+01	0.200E-02	0.270E-01	100.0	0.2
2	100.0	0.000E+00	0.000E+00	0.000E+00	0.000E+00	100.0	0.0
3	100.0	0.000E+00	0.000E+00	0.000E+00	0.000E+00	100.0	0.0
4	96.5	0.400E+00	0.896E+00	0.359E-02	0.317E-01	100.0	0.5
5	100.0	0.000E+00	0.000E+00	0.000E+00	0.000E+00	100.0	0.0
6	100.0	0.000E+00	0.000E+00	0.000E+00	0.000E+00	100.0	0.0

SYSTEM STATISTICS FOR SAMPLE PERIOD ENDING AT TIME 3000.00

BASE	SL%	B ORDERS /100 DAYS	AVG BO TIME IN DAYS	TWBO BO-DAYS/DAY	MSRT IN DAYS	OPERATIONAL AVAIL%	STD DEV%
1	89.2	0.700E+00	0.875E+00	0.613E-02	0.943E-01	100.0	0.3
2	89.7	0.700E+00	0.100E+01	0.700E-02	0.103E+00	100.0	0.3
3	100.0	0.000E+00	0.000E+00	0.000E+00	0.000E+00	100.0	0.0
4	81.6	0.230E+01	0.956E+00	0.220E-01	0.176E+00	99.9	0.7
5	88.7	0.700E+00	0.100E+01	0.700E-02	0.113E+00	100.0	0.3
6	90.7	0.500E+00	0.881E+00	0.441E-02	0.816E-01	100.0	0.2

SYSTEM STATISTICS FOR SAMPLE PERIOD ENDING AT TIME 4000.00

BASE	SL%	B ORDERS /100 DAYS	AVG BO TIME IN DAYS	TWBO BO-DAYS/DAY	MSRT IN DAYS	OPERATIONAL AVAIL%	STD DEV%
1	47.8	0.470E+01	0.720E+01	0.339E+00	0.376E+01	99.4	2.6
2	53.1	0.380E+01	0.485E+01	0.184E+00	0.227E+01	99.7	1.5
3	63.6	0.160E+01	0.761E+01	0.122E+00	0.277E+01	99.8	1.2
4	56.6	0.530E+01	0.469E+01	0.249E+00	0.204E+01	99.6	2.3
5	62.5	0.240E+01	0.564E+01	0.135E+00	0.212E+01	99.8	1.3
6	46.2	0.280E+01	0.714E+01	0.200E+00	0.384E+01	99.7	1.6

SYSTEM STATISTICS FOR SAMPLE PERIOD ENDING AT TIME 5000.00

BASE	SL%	B ORDERS /100 DAYS	AVG BO TIME IN DAYS	TWBO BO-DAYS/DAY	MSRT IN DAYS	OPERATIONAL AVAIL%	STD DEV%
1	5.3	0.710E+01	0.136E+02	0.964E+00	0.129E+02	98.4	4.4
2	13.9	0.620E+01	0.138E+02	0.859E+00	0.119E+02	98.7	4.0
3	9.4	0.290E+01	0.802E+01	0.232E+00	0.726E+01	99.6	1.8
4	15.0	0.910E+01	0.929E+01	0.845E+00	0.790E+01	98.6	4.1
5	9.7	0.560E+01	0.104E+02	0.584E+00	0.942E+01	99.1	2.9
6	16.4	0.460E+01	0.989E+01	0.455E+00	0.827E+01	99.2	2.8

SYSTEM STATISTICS FOR SAMPLE PERIOD ENDING AT TIME 6000.00

BASE	SL%	B ORDERS /100 DAYS	AVG BO TIME IN DAYS	TWBO BO-DAYS/DAY	MSRT IN DAYS	OPERATIONAL AVAIL%	STD DEV%
1	34.5	0.550E+01	0.763E+01	0.419E+00	0.499E+01	98.2	4.5
2	37.3	0.420E+01	0.847E+01	0.356E+00	0.531E+01	98.5	4.0
3	41.9	0.250E+01	0.521E+01	0.130E+00	0.303E+01	99.5	1.9
4	39.8	0.650E+01	0.108E+02	0.702E+00	0.650E+01	98.1	4.9
5	23.8	0.320E+01	0.880E+01	0.281E+00	0.670E+01	98.9	3.1
6	41.2	0.300E+01	0.611E+01	0.183E+00	0.359E+01	99.1	2.8

SYSTEM STATISTICS FOR SAMPLE PERIOD ENDING AT TIME 7000.00

BASE	SL%	B ORDERS /100 DAYS	AVG BO TIME IN DAYS	TWBO BO-DAYS/DAY	MSRT IN DAYS	OPERATIONAL AVAIL%	STD DEV%
1	1.6	0.620E+01	0.198E+02	0.123E+01	0.195E+02	97.3	5.5
2	6.8	0.820E+01	0.145E+02	0.119E+01	0.135E+02	97.7	5.2
3	0.0	0.270E+01	0.236E+02	0.636E+00	0.236E+02	99.0	2.8
4	0.9	0.114E+02	0.206E+02	0.235E+01	0.204E+02	96.2	7.5
5	4.9	0.580E+01	0.178E+02	0.103E+01	0.170E+02	98.2	4.2
6	3.4	0.570E+01	0.127E+02	0.726E+00	0.123E+02	98.6	3.8

SYSTEM STATISTICS FOR SAMPLE PERIOD ENDING AT TIME 8000.00

BASE	SL%	B ORDERS	AVG BO TIME	TWBO	MSRT	OPERATIONAL	
		/100 DAYS	IN DAYS	BO-DAYS/DAY	IN DAYS	AVAIL%	STD DEV%
1	0.0	0.710E+01	0.390E+02	0.277E+01	0.390E+02	95.5	7.8
2	0.0	0.610E+01	0.374E+02	0.228E+01	0.374E+02	96.2	6.8
3	0.0	0.390E+01	0.388E+02	0.151E+01	0.388E+02	97.9	4.8
4	0.0	0.790E+01	0.387E+02	0.306E+01	0.387E+02	94.3	9.5
5	0.0	0.560E+01	0.358E+02	0.200E+01	0.358E+02	96.8	6.1
6	0.0	0.550E+01	0.335E+02	0.184E+01	0.335E+02	97.2	6.0

SYSTEM STATISTICS FOR SAMPLE PERIOD ENDING AT TIME 9000.00

BASE	SL%	B ORDERS	AVG BO TIME	TWBO	MSRT	OPERATIONAL	
		/100 DAYS	IN DAYS	BO-DAYS/DAY	IN DAYS	AVAIL%	STD DEV%
1	0.0	0.680E+01	0.338E+02	0.230E+01	0.338E+02	94.4	8.6
2	0.0	0.620E+01	0.393E+02	0.244E+01	0.393E+02	94.9	7.8
3	0.0	0.460E+01	0.376E+02	0.173E+01	0.376E+02	97.0	6.0
4	0.0	0.900E+01	0.366E+02	0.330E+01	0.366E+02	92.6	10.7
5	0.0	0.490E+01	0.314E+02	0.154E+01	0.314E+02	96.1	6.8
6	0.0	0.540E+01	0.388E+02	0.209E+01	0.388E+02	96.1	6.8

SYSTEM STATISTICS FOR SAMPLE PERIOD ENDING AT TIME 10000.00

BASE	SL%	B ORDERS	AVG BO TIME	TWBO	MSRT	OPERATIONAL	
		/100 DAYS	IN DAYS	BO-DAYS/DAY	IN DAYS	AVAIL%	STD DEV%
1	0.0	0.690E+01	0.250E+02	0.172E+01	0.250E+02	93.8	8.8
2	1.4	0.680E+01	0.238E+02	0.162E+01	0.234E+02	94.4	7.9
3	0.0	0.380E+01	0.255E+02	0.970E+00	0.255E+02	96.6	6.1
4	0.0	0.890E+01	0.312E+02	0.278E+01	0.312E+02	91.6	11.0
5	0.0	0.550E+01	0.308E+02	0.170E+01	0.308E+02	95.4	7.4
6	0.0	0.620E+01	0.295E+02	0.183E+01	0.295E+02	95.3	7.8

SYSTEM STATISTICS FOR SAMPLE PERIOD ENDING AT TIME 11000.00

BASE	SL%	B ORDERS	AVG BO TIME	TWBO	MSRT	OPERATIONAL	
		/100 DAYS	IN DAYS	BO-DAYS/DAY	IN DAYS	AVAIL%	STD DEV%
1	0.0	0.670E+01	0.473E+02	0.317E+01	0.473E+02	81.3	9.6
2	0.0	0.700E+01	0.378E+02	0.264E+01	0.378E+02	83.3	10.3
3	0.0	0.390E+01	0.388E+02	0.151E+01	0.388E+02	90.7	8.2
4	0.0	0.780E+01	0.447E+02	0.349E+01	0.447E+02	78.7	11.9
5	0.0	0.420E+01	0.466E+02	0.196E+01	0.466E+02	87.8	8.6
6	0.0	0.590E+01	0.435E+02	0.257E+01	0.435E+02	84.4	7.9

SYSTEM STATISTICS FOR SAMPLE PERIOD ENDING AT TIME 12000.00

BASE	SL%	B ORDERS	AVG BO TIME	TWBO	MSRT	OPERATIONAL	
		/100 DAYS	IN DAYS	BO-DAYS/DAY	IN DAYS	AVAIL%	STD DEV%
1	12.7	0.620E+01	0.171E+02	0.106E+01	0.149E+02	87.4	10.3
2	8.9	0.510E+01	0.207E+02	0.106E+01	0.189E+02	88.5	10.5
3	17.0	0.390E+01	0.201E+02	0.785E+00	0.167E+02	93.0	7.5
4	4.9	0.980E+01	0.199E+02	0.195E+01	0.189E+02	83.3	12.2
5	6.3	0.450E+01	0.202E+02	0.909E+00	0.189E+02	91.2	8.4
6	14.6	0.410E+01	0.194E+02	0.796E+00	0.166E+02	89.8	8.8

SYSTEM STATISTICS FOR SAMPLE PERIOD ENDING AT TIME 13000.00

BASE	SL%	B ORDERS /100 DAYS	AVG BO TIME IN DAYS	TWBO BO-DAYS/DAY	MSRT IN DAYS	OPERATIONAL AVAIL%	STD DEV%
1	25.9	0.630E+01	0.715E+01	0.451E+00	0.530E+01	90.6	10.0
2	30.6	0.430E+01	0.635E+01	0.273E+00	0.440E+01	91.8	10.0
3	29.5	0.310E+01	0.514E+01	0.159E+00	0.362E+01	95.0	6.9
4	30.6	0.770E+01	0.109E+02	0.843E+00	0.759E+01	87.1	12.4
5	46.2	0.280E+01	0.112E+02	0.313E+00	0.602E+01	93.5	8.0
6	28.6	0.500E+01	0.146E+02	0.730E+00	0.104E+02	91.7	9.0

SYSTEM STATISTICS FOR SAMPLE PERIOD ENDING AT TIME 14000.00

BASE	SL%	B ORDERS /100 DAYS	AVG BO TIME IN DAYS	TWBO BO-DAYS/DAY	MSRT IN DAYS	OPERATIONAL AVAIL%	STD DEV%
1	8.2	0.670E+01	0.131E+02	0.875E+00	0.120E+02	91.6	9.3
2	8.7	0.630E+01	0.983E+01	0.620E+00	0.898E+01	92.8	9.3
3	6.7	0.280E+01	0.114E+02	0.320E+00	0.107E+02	95.7	6.4
4	8.4	0.980E+01	0.125E+02	0.122E+01	0.114E+02	88.3	11.8
5	1.6	0.610E+01	0.153E+02	0.936E+00	0.151E+02	93.6	7.7
6	8.3	0.550E+01	0.150E+02	0.825E+00	0.137E+02	92.4	8.5

SYSTEM STATISTICS FOR SAMPLE PERIOD ENDING AT TIME 15000.00

BASE	SL%	B ORDERS /100 DAYS	AVG BO TIME IN DAYS	TWBO BO-DAYS/DAY	MSRT IN DAYS	OPERATIONAL AVAIL%	STD DEV%
1	5.9	0.800E+01	0.107E+02	0.854E+00	0.100E+02	92.2	8.9
2	8.0	0.690E+01	0.137E+02	0.943E+00	0.126E+02	93.1	8.9
3	20.0	0.320E+01	0.935E+01	0.299E+00	0.748E+01	96.2	6.0
4	5.4	0.870E+01	0.189E+02	0.164E+01	0.178E+02	88.7	11.4
5	1.9	0.510E+01	0.189E+02	0.963E+00	0.185E+02	93.6	8.0
6	1.6	0.610E+01	0.227E+02	0.139E+01	0.223E+02	92.2	8.7

SYSTEM STATISTICS FOR SAMPLE PERIOD ENDING AT TIME 16000.00

BASE	SL%	B ORDERS /100 DAYS	AVG BO TIME IN DAYS	TWBO BO-DAYS/DAY	MSRT IN DAYS	OPERATIONAL AVAIL%	STD DEV%
1	21.8	0.430E+01	0.856E+01	0.368E+00	0.669E+01	93.1	8.5
2	42.9	0.360E+01	0.503E+01	0.181E+00	0.288E+01	94.0	8.5
3	44.8	0.160E+01	0.682E+01	0.109E+00	0.376E+01	96.7	5.7
4	49.6	0.620E+01	0.553E+01	0.343E+00	0.279E+01	90.2	11.1
5	29.2	0.460E+01	0.104E+02	0.479E+00	0.736E+01	94.3	7.6
6	35.9	0.410E+01	0.159E+02	0.652E+00	0.102E+02	92.9	8.4

SYSTEM STATISTICS FOR SAMPLE PERIOD ENDING AT TIME 17000.00

BASE	SL%	B ORDERS /100 DAYS	AVG BO TIME IN DAYS	TWBO BO-DAYS/DAY	MSRT IN DAYS	OPERATIONAL AVAIL%	STD DEV%
1	0.0	0.720E+01	0.164E+02	0.118E+01	0.164E+02	93.1	8.4
2	6.8	0.690E+01	0.153E+02	0.106E+01	0.143E+02	94.0	8.3
3	2.6	0.380E+01	0.160E+02	0.610E+00	0.156E+02	96.7	5.7
4	8.7	0.950E+01	0.144E+02	0.137E+01	0.132E+02	90.4	10.7
5	3.7	0.520E+01	0.177E+02	0.918E+00	0.170E+02	94.2	7.5
6	9.2	0.590E+01	0.166E+02	0.978E+00	0.150E+02	93.0	8.3

SYSTEM STATISTICS FOR SAMPLE PERIOD ENDING AT TIME 18000.00

BASE	SL%	B ORDERS /100 DAYS	AVG BO TIME IN DAYS	TWBO BO-DAYS/DAY	MSRT IN DAYS	OPERATIONAL AVAIL%	STD DEV%
1	2.7	0.720E+01	0.202E+02	0.145E+01	0.196E+02	92.8	8.2
2	0.0	0.690E+01	0.201E+02	0.139E+01	0.201E+02	93.6	8.2
3	2.2	0.450E+01	0.198E+02	0.891E+00	0.194E+02	96.4	5.7
4	0.0	0.920E+01	0.208E+02	0.191E+01	0.208E+02	90.1	10.5
5	0.0	0.560E+01	0.197E+02	0.110E+01	0.197E+02	94.1	7.4
6	0.0	0.550E+01	0.179E+02	0.986E+00	0.179E+02	93.1	8.0

SYSTEM STATISTICS FOR SAMPLE PERIOD ENDING AT TIME 19000.00

BASE	SL%	B ORDERS /100 DAYS	AVG BO TIME IN DAYS	TWBO BO-DAYS/DAY	MSRT IN DAYS	OPERATIONAL AVAIL%	STD DEV%
1	6.3	0.740E+01	0.130E+02	0.962E+00	0.122E+02	92.9	8.1
2	6.2	0.610E+01	0.157E+02	0.957E+00	0.147E+02	93.7	7.9
3	0.0	0.380E+01	0.148E+02	0.564E+00	0.148E+02	96.3	5.7
4	16.2	0.880E+01	0.136E+02	0.120E+01	0.114E+02	90.4	10.3
5	13.1	0.530E+01	0.119E+02	0.630E+00	0.103E+02	94.3	7.2
6	17.3	0.430E+01	0.136E+02	0.586E+00	0.113E+02	93.5	7.9

SYSTEM STATISTICS FOR SAMPLE PERIOD ENDING AT TIME 20000.00

BASE	SL%	B ORDERS /100 DAYS	AVG BO TIME IN DAYS	TWBO BO-DAYS/DAY	MSRT IN DAYS	OPERATIONAL AVAIL%	STD DEV%
1	0.0	0.790E+01	0.362E+02	0.286E+01	0.362E+02	91.8	8.8
2	0.0	0.640E+01	0.371E+02	0.237E+01	0.371E+02	92.8	8.4
3	0.0	0.320E+01	0.319E+02	0.102E+01	0.319E+02	96.1	6.0
4	0.0	0.910E+01	0.372E+02	0.339E+01	0.372E+02	89.2	10.9
5	0.0	0.530E+01	0.343E+02	0.182E+01	0.343E+02	93.7	7.5
6	0.0	0.470E+01	0.356E+02	0.167E+01	0.356E+02	93.1	7.9

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SYSTEM STATS FROM TIME CLEAR TO END. SAMPLE PERIOD (DAYS) = 10000.00

BASE	SL%	B ORDERS /100 DAYS	AVG BO TIME IN DAYS	TWBO BO-DAYS/DAY	MSRT IN DAYS	OPERATIONAL AVAIL%
1	7.5	0.748E+01	0.200E+02	0.136E+01	0.185E+02	91.0
2	9.9	0.663E+01	0.198E+02	0.119E+01	0.178E+02	92.0
3	10.9	0.376E+01	0.193E+02	0.658E+00	0.172E+02	95.4
4	12.8	0.955E+01	0.211E+02	0.183E+01	0.184E+02	88.0
5	9.7	0.542E+01	0.216E+02	0.107E+01	0.195E+02	93.3
6	11.0	0.573E+01	0.227E+02	0.118E+01	0.202E+02	92.0

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S L A M I I S U M M A R Y R E P O R T

SIMULATION PROJECT S6 3ECHELON 6 BASE BY CORNWALL

DATE 6/13/1990 RUN NUMBER 1 OF 1

CURRENT TIME 0.2000E+05
STATISTICAL ARRAYS CLEARED AT TIME 0.1000E+05

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TMS DLM	0.4266E+03	0.4645E+02	0.1089E+00	0.2778E+03	0.5666E+03	1553
TMS ILM	0.3029E+02	0.5802E+01	0.1916E+00	0.1554E+02	0.5570E+02	1225
AVG OP TIME B1	0.1987E+03	0.1909E+03	0.9611E+00	0.2585E+00	0.1106E+04	740
SYS1 DOWN TIME	0.1779E+02	0.1676E+02	0.9423E+00	0.0000E+00	0.6907E+02	744
TMS BASE1	0.9753E+01	0.2986E+01	0.3062E+00	0.3874E+01	0.2283E+02	228
AVG OP TIME B2	0.2241E+03	0.2241E+03	0.1000E+01	0.3162E-01	0.1480E+04	667
SYS2 DOWN TIME	0.1730E+02	0.1645E+02	0.9510E+00	0.0000E+00	0.6811E+02	664
TMS BASE2	0.9994E+01	0.3245E+01	0.3247E+00	0.4838E+01	0.2152E+02	197
SYS3 DOWN TIME	0.1637E+02	0.1596E+02	0.9748E+00	0.0000E+00	0.6197E+02	383
TMS BASE3	0.9903E+01	0.3109E+01	0.3139E+00	0.4743E+01	0.2177E+02	111
AVG OP TIME B4	0.1420E+03	0.1420E+03	0.9999E+00	0.1389E+00	0.8744E+03	1006
SYS4 DOWN TIME	0.1727E+02	0.1686E+02	0.9761E+00	0.0000E+00	0.6889E+02	1005
TMS BASE4	0.1023E+02	0.3026E+01	0.2958E+00	0.4295E+01	0.2310E+02	295
AVG OP TIME B5	0.2708E+03	0.2633E+03	0.9722E+00	0.4673E-01	0.1902E+04	545
SYS5 DOWN TIME	0.1832E+02	0.1668E+02	0.9106E+00	0.0000E+00	0.6848E+02	547
TMS BASE5	0.1014E+02	0.3009E+01	0.2967E+00	0.4844E+01	0.2088E+02	144
AVG OP TIME B6	0.2521E+03	0.2451E+03	0.9723E+00	0.7737E+00	0.1556E+04	582
SYS6 DOWN TIME	0.1914E+02	0.1740E+02	0.9094E+00	0.0000E+00	0.7445E+02	584
TMS BASE6	0.9882E+01	0.2844E+01	0.2878E+00	0.5461E+01	0.2134E+02	172

FILE STATISTICS

FILE NUMBER	LABEL/TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	DU1 QUEUE	1.3074	1.4154	8	2	15.4716
2	DU2 QUEUE	1.1487	1.3447	7	4	14.7268
3	DU3 QUEUE	0.6267	0.9532	6	2	11.8245
4	DU4 QUEUE	1.7306	1.7373	10	4	15.9205
5	DU5 QUEUE	1.0017	1.1926	7	1	16.3944
6	DU6 QUEUE	1.1095	1.2696	7	1	16.3644
7		0.0000	0.0000	0	0	0.0000
8	DI QUEUE	16.7596	12.1906	69	14	48.3542
9	SI QUEUE	0.0010	0.0380	2	0	0.0084
10	IIMQ QUEUE	0.0025	0.0501	1	0	0.0206
11	SU1 QUEUE	0.1346	0.5289	6	0	1.5970
12	SU2 QUEUE	0.1329	0.4484	4	0	1.7132
13	SU3 QUEUE	0.1300	0.3956	4	0	2.4630
14	SU4 QUEUE	0.1538	0.5214	5	0	1.4197
15	SU5 QUEUE	0.1102	0.3497	3	0	1.8065
16	SU6 QUEUE	0.1771	0.5308	4	0	2.6159
17		0.0000	0.0000	0	0	0.0000
18		0.0000	0.0000	0	0	0.0000
19		0.0000	0.0000	0	0	0.0000
20		0.0000	0.0000	0	0	0.0000
21	CMQ1 QUEUE	0.0000	0.0000	0	0	0.0000
22	CMQ2 QUEUE	0.0000	0.0000	0	0	0.0000
23	QUEUE	0.0000	0.0000	0	0	0.0000
24	CMQ4 QUEUE	0.0000	0.0000	0	0	0.0000
25	CMQ5 QUEUE	0.0000	0.0000	0	0	0.0000
26	CMQ6 QUEUE	0.0000	0.0000	0	0	0.0000
27		0.0000	0.0000	0	0	0.0000
28	DD QUEUE	6.0762	5.2182	21	14	19.6830
29	SD QUEUE	0.1031	0.4389	5	0	0.6642
30	DIMQ QUEUE	52.3349	6.8052	68	60	324.4566
31	SYS1 QUEUE	0.0000	0.0000	0	0	0.0000
32	SYS2 QUEUE	0.0000	0.0000	0	0	0.0000
33	SYS3 QUEUE	0.0000	0.0000	0	0	0.0000
34	SYS4 QUEUE	0.0000	0.0000	0	0	0.0000
35	SYS5 QUEUE	0.0000	0.0000	0	0	0.0000
36	SYS6 QUEUE	0.0000	0.0000	0	0	0.0000
37	CALENDAR	110.7197	5.6829	131	104	11.0805

REGULAR ACTIVITY STATISTICS

ACTIVITY INDEX/LABEL	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL	ENTITY COUNT
7 # SD TO IIM	0.0002	0.0141	1	0	1
8 # DIM - U1	0.1110	0.3340	3	0	278
9 # DIM - U2	0.1000	0.3160	2	0	250
10 # DIM - U3	0.0652	0.2525	2	0	163
11 # DIM - U4	0.1508	0.3814	3	0	377
12 # DIM - U5	0.0952	0.3103	3	0	238
13 # DIM - U6	0.0988	0.3175	3	0	247
15 RESUP I FM D	0.0000	0.0000	1	0	4
16 # IIM - U1	0.0432	0.2078	2	0	216
17 # IIM - U2	0.0438	0.2101	2	0	219
18 # IIM - U3	0.0402	0.2024	2	0	201
19 # IIM - U4	0.0519	0.2302	2	0	260
20 # IIM - U5	0.0290	0.1695	2	0	145
21 # IIM - U6	0.0372	0.1974	2	0	186
23 EX SI TO DIM	0.0000	0.0000	0	0	0
24 DIM REPAIR 1	0.0000	0.0000	1	0	300
25 IIM REPAIR 1	0.0000	0.0000	1	0	212
26 OIM REPAIR 1	0.0000	0.0000	1	0	228
27 #BO BASE 1	0.0000	0.0000	1	0	679
28 U1-TRY LRS	0.0000	0.0000	1	0	641
30 LRS1-2	0.0019	0.0435	1	0	19
31 LRS1-3	0.0016	0.0400	2	0	16
32 LRS1-4	0.0034	0.0592	2	0	34
33 LRS1-5	0.0008	0.0283	1	0	8
34 LRS1-6	0.0022	0.0469	1	0	22
36 EX S1 TO IIM	0.0000	0.0000	0	0	0
37 DIM REPAIR 2	0.0000	0.0000	1	0	255
38 IIM REPAIR 2	0.0000	0.0000	1	0	213
39 OIM2 REPAIR	0.0000	0.0000	1	0	199
40 # BO BASE 2	0.0000	0.0000	1	0	595
41 U2-TRY LRS	0.0000	0.0000	1	0	569
42 # LRS2-1	0.0025	0.0499	1	0	25
44 # LRS2-3	0.0014	0.0374	1	0	14
45 # LRS2-4	0.0031	0.0556	1	0	31
46 # LRS2-5	0.0021	0.0458	1	0	21
47 # LRS2-6	0.0021	0.0458	1	0	21
49 EX S2 TO IIM	0.0000	0.0000	0	0	0
50 DIM REPAIR 3	0.0000	0.0000	1	0	159
51 IIM REPAIR 3	0.0000	0.0000	1	0	114
52 OIM3 REPAIR	0.0000	0.0000	1	0	111
53 # BO BASE 3	0.0000	0.0000	1	0	338
54 U3-TRY LRS	0.0000	0.0000	1	0	321
55 # LRS3-1	0.0042	0.0647	1	0	42
56 # LRS3-2	0.0036	0.0599	1	0	36
58 # LRS3-4	0.0031	0.0556	1	0	31
59 # LRS3-5	0.0021	0.0458	1	0	21
60 # LRS3-6	0.0015	0.0387	1	0	15
62 EX S3 TO IIM	0.0000	0.0000	0	0	0
63 DIM REPAIR 4	0.0000	0.0000	1	0	384
64 IIM REPAIR 4	0.0000	0.0000	1	0	327
65 OIM4 REPAIR	0.0000	0.0000	1	0	295
66 # BO BASE 4	0.0000	0.0000	1	0	866
67 U4-TRY LRS	0.0000	0.0000	1	0	826
68 # LRS4-1	0.0019	0.0435	1	0	19
69 # LRS4-2	0.0022	0.0469	1	0	22
70 # LRS4-3	0.0012	0.0346	1	0	12
72 # LRS4-5	0.0018	0.0424	1	0	18
73 # LRS4-6	0.0007	0.0264	1	0	7
75 EX S4 TO IIM	0.0000	0.0000	0	0	0
76 DIM REPAIR 5	0.0000	0.0000	1	0	217
77 IIM REPAIR 5	0.0000	0.0000	1	0	184
78 OIM2 REPAIR	0.0000	0.0000	1	0	144
79 # BO BASE 5	0.0000	0.0000	1	0	487
80 U5-TRY LRS	0.0000	0.0000	1	0	458
81 # LRS5-1	0.0012	0.0346	1	0	12
82 # LRS5-2	0.0015	0.0387	1	0	15
83 # LRS5-3	0.0006	0.0245	1	0	6
84 # LRS5-4	0.0023	0.0479	1	0	23
86 # LRS5-6	0.0007	0.0264	1	0	7
88 EX S5 TO IIM	0.0000	0.0000	0	0	0

89 # BO BASE 6	0.0000	0.0000	1	0	511
90 U6-TRY LRS	0.0000	0.0000	1	0	492
91 # LRS6-1	0.0023	0.0479	1	0	23
92 # LRS6-2	0.0018	0.0424	1	0	18
93 # LRS6-3	0.0005	0.0224	1	0	5
94 # LRS6-4	0.0032	0.0575	2	0	32
95 # LRS6-5	0.0015	0.0387	1	0	15
97 EX S6 TO IIM	0.0000	0.0000	0	0	0

SERVICE ACTIVITY STATISTICS

ACTIVITY ENTITY INDEX	START NODE OR ACTIVITY LABEL	SERVER CAPACITY	AVERAGE UTILIZATION	STANDARD DEVIATION	CURRENT UTILIZATION	AVERAGE BLOCKAGE	MAXIMUM IDLE TIME/SERVERS	MAXIMUM BUSY TIME/SERVERS	COUNT
0	SNDD SELECT	1	0.0000	0.0000	0	0.0000	37.7150	0.0000	
14	DIM REPAIR	14	14.0000	0.0000	14	0.0000	0.0000	14.0000	1553
0	SNDI SELECT	1	0.0000	0.0000	0	0.0000	56.8170	0.0000	
22	IIM REPAIR	9	3.7069	1.8588	3	0.0000	9.0000	9.0000	1225
1	OP SYS U1	20	14.6926	1.4154	14	0.0000	12.0000	16.0000	740
0	SND1 SELECT	1	0.0000	0.0000	0	0.0000	76.7319	0.0000	
35	OIM1 REPAIR	5	0.2224	0.4688	0	0.0000	5.0000	3.0000	228
2	OP SYS U2	20	14.8513	1.3447	12	0.0000	11.0000	16.0000	667
0	SND2 SELECT	1	0.0000	0.0000	0	0.0000	109.0545	0.0000	
48	OIM2 REPAIR	5	0.1975	0.4431	2	0.0000	5.0000	3.0000	197
3	OP SYS U3	20	15.3733	0.9532	14	0.0000	10.0000	16.0000	384
0	SYS3 QUEUE	1	0.0000	0.0000	0	0.0000	9999.9900	0.0000	
0	SND3 SELECT	1	0.0000	0.0000	0	0.0000	147.4549	0.0000	
4	OP SYS U4	20	14.2694	1.7373	12	0.0000	14.0000	16.0000	1006
0	SND4 SELECT	1	0.0000	0.0000	0	0.0000	71.9307	0.0000	
74	OIM4 REPAIR	5	0.3017	0.5658	0	0.0000	5.0000	4.0000	295
5	OP SYS U5	20	14.9983	1.1926	15	0.0000	11.0000	16.0000	545
0	SND5 SELECT	1	0.0000	0.0000	0	0.0000	93.8979	0.0000	
87	OIM5 REPAIR	5	0.1460	0.3897	0	0.0000	5.0000	3.0000	144
6	OP SYS U6	20	14.8905	1.2696	15	0.0000	11.0000	16.0000	582
0	SND6 SELECT	1	0.0000	0.0000	0	0.0000	89.1992	0.0000	
96	OIM6 REPAIR	5	0.1700	0.4084	0	0.0000	5.0000	3.0000	172
61	OIM3 REPAIR	5	0.1099	0.3286	0	0.0000	5.0000	3.0000	111

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HISTOGRAM NUMBER 1

TMS DIM

```
 OBSV   RELA   CUML     UPPER
 FREQ   FREQ   FREQ  CELL LIMIT   0         20        40        60        80        100
                                  +    +    +    +    +    +    +    +    +    +    +
    0  0.000  0.000  0.2000E+03   +                                                 +
    0  0.000  0.000  0.2100E+03   +                                                 +
    0  0.000  0.000  0.2200E+03   +                                                 +
    0  0.000  0.000  0.2300E+03   +                                                 +
    0  0.000  0.000  0.2400E+03   +                                                 +
    0  0.000  0.000  0.2500E+03   +                                                 +
    0  0.000  0.000  0.2600E+03   +                                                 +
    0  0.000  0.000  0.2700E+03   +                                                 +
    1  0.001  0.001  0.2800E+03   +                                                 +
    0  0.000  0.001  0.2900E+03   +                                                 +
    0  0.000  0.001  0.3000E+03   +                                                 +
    2  0.001  0.002  0.3100E+03   +                                                 +
    3  0.002  0.004  0.3200E+03   +                                                 +
   12  0.008  0.012  0.3300E+03   +C                                                +
   22  0.014  0.026  0.3400E+03   +*                                                +
   44  0.028  0.054  0.3500E+03   +* C                                              +
   35  0.023  0.077  0.3600E+03   +*  C                                             +
   63  0.041  0.117  0.3700E+03   +**   C                                           +
   77  0.050  0.167  0.3800E+03   +**     C                                         +
   99  0.064  0.231  0.3900E+03   +***        C                                     +
  108  0.070  0.300  0.4000E+03   +***           C                                  +
  110  0.071  0.371  0.4100E+03   +****              C                              +
  124  0.080  0.451  0.4200E+03   +****                  C                          +
  123  0.079  0.530  0.4300E+03   +****                     C                       +
  123  0.079  0.609  0.4400E+03   +****                         C                   +
  120  0.077  0.686  0.4500E+03   +****                             C               +
   99  0.064  0.750  0.4600E+03   +***                                  C           +
   93  0.060  0.810  0.4700E+03   +***                                     C        +
   76  0.049  0.859  0.4800E+03   +**                                        C      +
   75  0.048  0.907  0.4900E+03   +**                                          C    +
   54  0.035  0.942  0.5000E+03   +**                                            C  +
   35  0.023  0.965  0.5100E+03   +*                                              C +
   26  0.017  0.981  0.5200E+03   +*                                               C+
   13  0.008  0.990  0.5300E+03   +                                                C+
   11  0.007  0.997  0.5400E+03   +                                                 C
    3  0.002  0.999  0.5500E+03   +                                                 C
    1  0.001  0.999  0.5600E+03   +                                                 C
    1  0.001  1.000  0.5700E+03   +                                                 C
    0  0.000  1.000  0.5800E+03   +                                                 C
    0  0.000  1.000  0.5900E+03   +                                                 C
    0  0.000  1.000  0.6000E+03   +                                                 C
    0  0.000  1.000     INF       +                                                 C
 ----                             +    +    +    +    +    +    +    +    +    +    +
 1553                             0         20        40        60        80        100
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TMS DIM	0.4266E+03	0.4645E+02	0.1089E+00	0.2778E+03	0.5666E+03	1553

1

HISTOGRAM NUMBER 2

TMS ILM

```
OBSV   RELA   CUML     UPPER
FREQ   FREQ   FREQ   CELL LIMIT     0         20        40        60        80        100
                                    +    +    +    +    +    +    +    +    +    +    +
   0  0.000  0.000  0.0000E+00      +                                                 +
   0  0.000  0.000  0.3000E+01      +                                                 +
   0  0.000  0.000  0.6000E+01      +                                                 +
   0  0.000  0.000  0.9000E+01      +                                                 +
   0  0.000  0.000  0.1200E+02      +                                                 +
   0  0.000  0.000  0.1500E+02      +                                                 +
   9  0.007  0.007  0.1800E+02      +                                                 +
  35  0.029  0.036  0.2100E+02      +*C                                               +
 114  0.093  0.129  0.2400E+02      +*****C                                           +
 201  0.164  0.293  0.2700E+02      +********      C                                  +
 268  0.219  0.512  0.3000E+02      +***********              C                       +
 242  0.198  0.709  0.3300E+02      +**********                        C              +
 168  0.137  0.847  0.3600E+02      +*******                                  C       +
  99  0.081  0.927  0.3900E+02      +****                                         C   +
  49  0.040  0.967  0.4200E+02      +**                                             C +
  21  0.017  0.984  0.4500E+02      +*                                               C+
  10  0.008  0.993  0.4800E+02      +                                                 C
   4  0.003  0.996  0.5100E+02      +                                                 C
   2  0.002  0.998  0.5400E+02      +                                                 C
   3  0.002  1.000  0.5700E+02      +                                                 C
   0  0.000  1.000  0.6000E+02      +                                                 C
   0  0.000  1.000  0.6300E+02      +                                                 C
   0  0.000  1.000  0.6600E+02      +                                                 C
   0  0.000  1.000  0.6900E+02      +                                                 C
   0  0.000  1.000  0.7200E+02      +                                                 C
   0  0.000  1.000  0.7500E+02      +                                                 C
   0  0.000  1.000     INF          +                                                 C
 ----                               +    +    +    +    +    +    +    +    +    +    +
1225                                0         20        40        60        80        100
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

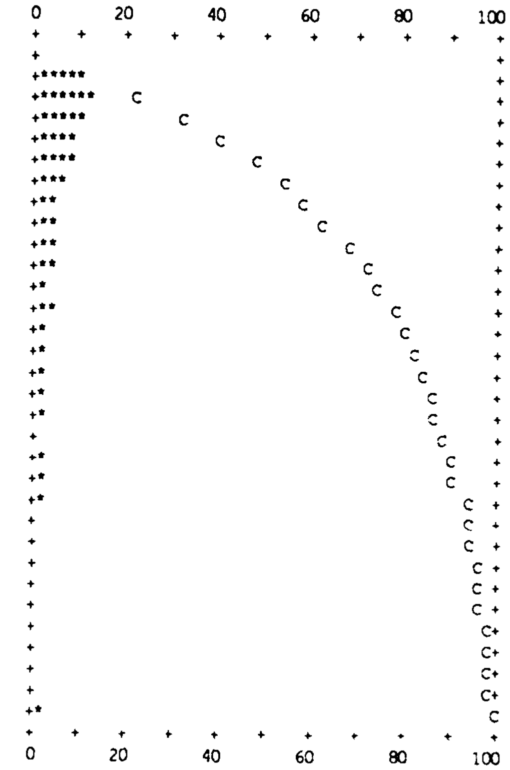
	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TMS ILM	0.3029E+02	0.5802E+01	0.1916E+00	0.1554E+02	0.5570E+02	1225

1

HISTOGRAM NUMBER 3

AVG OP TIME B1

OBSV FREQ	RELA FREQ	CUML FREQ	UPPER CELL LIMIT
0	0.000	0.000	0.0000E+00
81	0.109	0.109	0.2500E+02
85	0.115	0.224	0.5000E+02
69	0.093	0.318	0.7500E+02
57	0.077	0.395	0.1000E+03
61	0.082	0.477	0.1250E+03
46	0.062	0.539	0.1500E+03
29	0.039	0.578	0.1750E+03
37	0.050	0.628	0.2000E+03
33	0.045	0.673	0.2250E+03
28	0.038	0.711	0.2500E+03
21	0.028	0.739	0.2750E+03
26	0.035	0.774	0.3000E+03
20	0.027	0.801	0.3250E+03
14	0.019	0.820	0.3500E+03
8	0.011	0.831	0.3750E+03
15	0.020	0.851	0.4000E+03
10	0.014	0.865	0.4250E+03
7	0.009	0.874	0.4500E+03
13	0.018	0.892	0.4750E+03
12	0.016	0.908	0.5000E+03
18	0.024	0.932	0.5250E+03
7	0.009	0.942	0.5500E+03
6	0.008	0.950	0.5750E+03
3	0.004	0.954	0.6000E+03
7	0.009	0.964	0.6250E+03
2	0.003	0.966	0.6500E+03
3	0.004	0.970	0.6750E+03
4	0.005	0.976	0.7000E+03
4	0.005	0.981	0.7250E+03
2	0.003	0.984	0.7500E+03
12	0.016	1.000	INF
740			



STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
AVG OP TIME B1	0.1387E+03	0.1909E+03	0.9611E+00	0.2585E+00	0.1106E+04	740

1

HISTOGRAM NUMBER 4

SYS1 DOWN TIME

```
OBSV   RELA    CUML       UPPER
FREQ   FREQ    FREQ    CELL LIMIT   0         20        40        60        80        100
                                    +    +    +    +    +    +    +    +    +    +    +
  61   0.082   0.082   0.0000E+00   +****                                             +
 164   0.220   0.302   0.5000E+01   +***********   C                                  +
  93   0.125   0.427   0.1000E+02   +******              C                            +
  89   0.120   0.547   0.1500E+02   +******                    C                      +
  73   0.098   0.645   0.2000E+02   +*****                          C                 +
  39   0.052   0.698   0.2500E+02   +***                               C              +
  56   0.075   0.773   0.3000E+02   +****                                  C          +
  43   0.058   0.831   0.3500E+02   +***                                      C       +
  31   0.042   0.872   0.4000E+02   +**                                         C     +
  31   0.042   0.914   0.4500E+02   +**                                           C   +
  17   0.023   0.937   0.5000E+02   +*                                             C  +
  17   0.023   0.960   0.5500E+02   +*                                              C +
  15   0.020   0.980   0.6000E+02   +*                                               C+
  12   0.016   0.996   0.6500E+02   +*                                                C
   3   0.004   1.000   0.7000E+02   +                                                 C
   0   0.000   1.000   0.7500E+02   +                                                 C
   0   0.000   1.000   0.8000E+02   +                                                 C
   0   0.000   1.000   0.8500E+02   +                                                 C
   0   0.000   1.000   0.9000E+02   +                                                 C
   0   0.000   1.000   0.9500E+02   +                                                 C
   0   0.000   1.000   0.1000E+03   +                                                 C
   0   0.000   1.000   0.1050E+03   +                                                 C
   0   0.000   1.000   0.1100E+03   +                                                 C
   0   0.000   1.000   0.1150E+03   +                                                 C
   0   0.000   1.000   0.1200E+03   +                                                 C
   0   0.000   1.000   0.1250E+03   +                                                 C
   0   0.000   1.000          INF   +                                                 C
----                                +    +    +    +    +    +    +    +    +    +    +
 744                                0         20        40        60        80        100
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
SYS1 DOWN TIME	0.1779E+02	0.1676E+02	0.9423E+00	0.0000E+00	0.6907E+02	744

1

HISTOGRAM NUMBER 5

TMS BASE1

```
  OBSV    RELA    CUML        UPPER
  FREQ    FREQ    FREQ     CELL LIMIT    0        20        40        60        80       100
                                         +    +    +    +    +    +    +    +    +    +    +
     0   0.000   0.000    0.0000E+00     +                                                 +
     0   0.000   0.000    0.2000E+01     +                                                 +
     1   0.004   0.004    0.4000E+01     +                                                 +
     8   0.035   0.039    0.6000E+01     +**                                               +
    67   0.294   0.333    0.8000E+01     +*************** C                                +
    63   0.276   0.610    0.1000E+02     +**************               C                   +
    39   0.171   0.781    0.1200E+02     +*********                             C          +
    29   0.127   0.908    0.1400E+02     +******                                      C    +
    14   0.061   0.969    0.1600E+02     +***                                            C +
     3   0.013   0.982    0.1800E+02     +*                                               C+
     3   0.013   0.996    0.2000E+02     +*                                                C
     0   0.000   0.996    0.2200E+02     +                                                 C
     1   0.004   1.000    0.2400E+02     +                                                 C
     0   0.000   1.000    0.2600E+02     +                                                 C
     0   0.000   1.000    0.2800E+02     +                                                 C
     0   0.000   1.000    0.3000E+02     +                                                 C
     0   0.000   1.000    0.3200E+02     +                                                 C
     0   0.000   1.000    0.3400E+02     +                                                 C
     0   0.000   1.000    0.3600E+02     +                                                 C
     0   0.000   1.000    0.3800E+02     +                                                 C
     0   0.000   1.000    0.4000E+02     +                                                 C
     0   0.000   1.000       INF         +                                                 C
  ----                                   +    +    +    +    +    +    +    +    +    +    +
   228                                   0        20        40        60        80       100
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

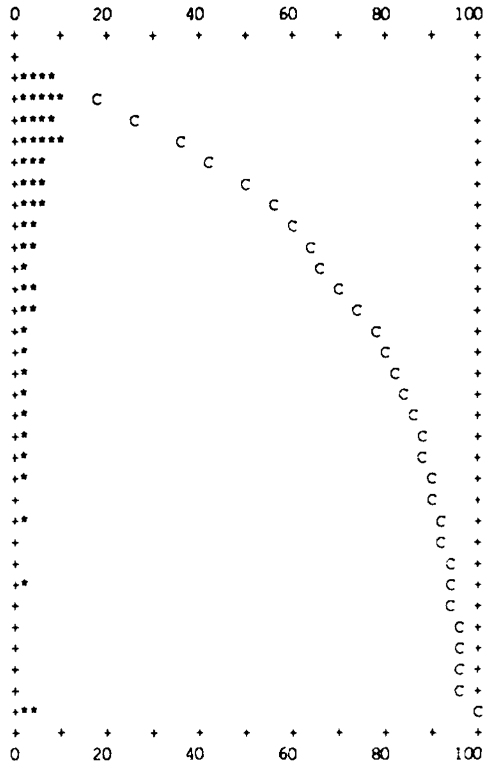
	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TMS BASE1	0.9753E+01	0.2986E+01	0.3062E+00	0.3874E+01	0.2283E+02	228

1

HISTOGRAM NUMBER 6

AVG OP TIME B2

OBSV FREQ	RELA FREQ	CUML FREQ	UPPER CELL LIMIT
0	0.000	0.000	0.0000E+00
57	0.085	0.085	0.2500E+02
61	0.091	0.177	0.5000E+02
59	0.088	0.265	0.7500E+02
68	0.102	0.367	0.1000E+03
37	0.055	0.423	0.1250E+03
46	0.069	0.492	0.1500E+03
45	0.067	0.559	0.1750E+03
24	0.036	0.595	0.2000E+03
28	0.042	0.637	0.2250E+03
20	0.030	0.667	0.2500E+03
25	0.037	0.705	0.2750E+03
28	0.042	0.747	0.3000E+03
16	0.024	0.771	0.3250E+03
19	0.028	0.799	0.3500E+03
15	0.022	0.822	0.3750E+03
10	0.015	0.837	0.4000E+03
11	0.016	0.853	0.4250E+03
14	0.021	0.874	0.4500E+03
8	0.012	0.886	0.4750E+03
8	0.012	0.898	0.5000E+03
6	0.009	0.907	0.5250E+03
8	0.012	0.919	0.5500E+03
6	0.009	0.928	0.5750E+03
5	0.007	0.936	0.6000E+03
7	0.010	0.946	0.6250E+03
1	0.001	0.948	0.6500E+03
2	0.003	0.951	0.6750E+03
2	0.003	0.954	0.7000E+03
4	0.006	0.960	0.7250E+03
3	0.004	0.964	0.7500E+03
24	0.036	1.000	INF
667			



STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
AVG OP TIME B2	0.2241E+03	0.2241E+03	0.1000E+01	0.3162E-01	0.1480E+04	667

1

HISTOGRAM NUMBER 7

SYS2 DOWN TIME

```
OBSV   RELA    CUML    UPPER
FREQ   FREQ    FREQ    CELL LIMIT    0         20        40        60        80        100
                                     +    +    +    +    +    +    +    +    +    +    +
  72   0.108   0.108   0.0000E+00    +*****                                            +
 135   0.203   0.312   0.5000E+01    +***********    C                                 +
  85   0.128   0.440   0.1000E+02    +******               C                           +
  69   0.104   0.544   0.1500E+02    +*****                     C                      +
  55   0.083   0.627   0.2000E+02    +****                          C                  +
  42   0.063   0.690   0.2500E+02    +***                              C               +
  65   0.098   0.788   0.3000E+02    +*****                                 C          +
  29   0.044   0.831   0.3500E+02    +**                                       C       +
  32   0.048   0.880   0.4000E+02    +**                                         C     +
  22   0.033   0.913   0.4500E+02    +**                                           C   +
  28   0.042   0.955   0.5000E+02    +**                                             C +
  13   0.020   0.974   0.5500E+02    +*                                               C+
   7   0.011   0.985   0.6000E+02    +*                                               C+
   8   0.012   0.997   0.6500E+02    +*                                                C
   2   0.003   1.000   0.7000E+02    +                                                 C
   0   0.000   1.000   0.7500E+02    +                                                 C
   0   0.000   1.000   0.8000E+02    +                                                 C
   0   0.000   1.000   0.8500E+02    +                                                 C
   0   0.000   1.000   0.9000E+02    +                                                 C
   0   0.000   1.000   0.9500E+02    +                                                 C
   0   0.000   1.000   0.1000E+03    +                                                 C
   0   0.000   1.000   0.1050E+03    +                                                 C
   0   0.000   1.000   0.1100E+03    +                                                 C
   0   0.000   1.000   0.1150E+03    +                                                 C
   0   0.000   1.000   0.1200E+03    +                                                 C
   0   0.000   1.000   0.1250E+03    +                                                 C
   0   0.000   1.000   INF           +                                                 C
 ---                                 +    +    +    +    +    +    +    +    +    +    +
 664                                 0         20        40        60        80        100
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
SYS2 DOWN TIME	0.1730E+02	0.1645E+02	0.9510E+00	0.0000E+00	0.6811E+02	664

1

HISTOGRAM NUMBER 9

SYS3 DOWN TIME

```
OBSV  RELA   CUML   UPPER
FREQ  FREQ   FREQ   CELL LIMIT   0         20        40        60        80        100
                                 +    +    +    +    +    +    +    +    +    +    +
  46  0.120  0.120  0.0000E+00   +******                                           +
  83  0.217  0.337  0.5000E+01   +***********     C                                +
  48  0.125  0.462  0.1000E+02   +******                C                          +
  48  0.125  0.587  0.1500E+02   +******                      C                    +
  26  0.068  0.655  0.2000E+02   +***                             C                +
  16  0.042  0.697  0.2500E+02   +**                                C              +
  32  0.084  0.781  0.3000E+02   +****                                  C          +
  19  0.050  0.830  0.3500E+02   +**                                       C       +
  24  0.063  0.893  0.4000E+02   +***                                         C    +
  14  0.037  0.930  0.4500E+02   +**                                           C   +
  13  0.034  0.963  0.5000E+02   +**                                             C +
   6  0.016  0.979  0.5500E+02   +*                                               C+
   7  0.018  0.997  0.6000E+02   +*                                                C
   1  0.003  1.000  0.6500E+02   +                                                 C
   0  0.000  1.000  0.7000E+02   +                                                 C
   0  0.000  1.000  0.7500E+02   +                                                 C
   0  0.000  1.000  0.8000E+02   +                                                 C
   0  0.000  1.000  0.8500E+02   +                                                 C
   0  0.000  1.000  0.9000E+02   +                                                 C
   0  0.000  1.000  0.9500E+02   +                                                 C
   0  0.000  1.000  0.1000E+03   +                                                 C
   0  0.000  1.000  0.1050E+03   +                                                 C
   0  0.000  1.000  0.1100E+03   +                                                 C
   0  0.000  1.000  0.1150E+03   +                                                 C
   0  0.000  1.000  0.1200E+03   +                                                 C
   0  0.000  1.000  0.1250E+03   +                                                 C
   0  0.000  1.000     INF       +                                                 C
 ---                             +    +    +    +    +    +    +    +    +    +    +
 383                             0         20        40        60        80        100
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
SYS3 DOWN TIME	0.1637E+02	0.1596E+02	0.9748E+00	0.0000E+00	0.6197E+02	383

1

HISTOGRAM NUMBER 12

SYS4 DOWN TIME

```
OBSV   RELA   CUML     UPPER
FREQ   FREQ   FREQ   CELL LIMIT    0        20        40        60        80        100
                                   +    +    +    +    +    +    +    +    +    +    +
 140  0.139  0.139   0.0000E+00    +*******                                          +
 206  0.205  0.344   0.5000E+01    +**********      C                                +
 100  0.100  0.444   0.1000E+02    +*****                C                           +
 103  0.102  0.546   0.1500E+02    +*****                     C                      +
  84  0.084  0.630   0.2000E+02    +****                          C                  +
  72  0.072  0.701   0.2500E+02    +****                             C               +
  69  0.069  0.770   0.3000E+02    +***                                  C           +
  52  0.052  0.822   0.3500E+02    +***                                    C         +
  50  0.050  0.872   0.4000E+02    +**                                        C      +
  60  0.060  0.931   0.4500E+02    +***                                          C   +
  19  0.019  0.950   0.5000E+02    +*                                             C  +
  16  0.016  0.966   0.5500E+02    +*                                             C  +
  16  0.016  0.982   0.6000E+02    +*                                              C+
  15  0.015  0.997   0.6500E+02    +*                                                C
   3  0.003  1.000   0.7000E+02    +                                                 C
   0  0.000  1.000   0.7500E+02    +                                                 C
   0  0.000  1.000   0.8000E+02    +                                                 C
   0  0.000  1.000   0.8500E+02    +                                                 C
   0  0.000  1.000   0.9000E+02    +                                                 C
   0  0.000  1.000   0.9500E+02    +                                                 C
   0  0.000  1.000   0.1000E+03    +                                                 C
   0  0.000  1.000   0.1050E+03    +                                                 C
   0  0.000  1.000   0.1100E+03    +                                                 C
   0  0.000  1.000   0.1150E+03    +                                                 C
   0  0.000  1.000   0.1200E+03    +                                                 C
   0  0.000  1.000   0.1250E+03    +                                                 C
   0  0.000  1.000      INF        +                                                 C
----                               +    +    +    +    +    +    +    +    +    +    +
1005                               0        20        40        60        80        100
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
SYS4 DOWN TIME	0.1727E+02	0.1686E+02	0.9761E+00	0.0000E+00	0.6889E+02	1005

1

HISTOGRAM NUMBER 15

SYS5 DOWN TIME

```
OBSV    RELA    CUML    UPPER
FREQ    FREQ    FREQ    CELL LIMIT     0        20        40        60        80        100
                                       +    +    +    +    +    +    +    +    +    +    +
  58   0.106   0.106   0.0000E+00      +*****                                            +
 103   0.188   0.294   0.5000E+01      +*********     C                                  +
  69   0.126   0.420   0.1000E+02      +******              C                            +
  61   0.112   0.532   0.1500E+02      +******                    C                      +
  41   0.075   0.607   0.2000E+02      +****                         C                   +
  40   0.073   0.680   0.2500E+02      +****                             C               +
  36   0.066   0.746   0.3000E+02      +***                                 C            +
  36   0.066   0.812   0.3500E+02      +***                                     C        +
  26   0.048   0.859   0.4000E+02      +**                                        C      +
  29   0.053   0.912   0.4500E+02      +***                                          C   +
  25   0.046   0.958   0.5000E+02      +**                                             C +
   8   0.015   0.973   0.5500E+02      +*                                               C+
   9   0.016   0.989   0.6000E+02      +*                                               C+
   4   0.007   0.996   0.6500E+02      +                                                 C
   2   0.004   1.000   0.7000E+02      +                                                 C
   0   0.000   1.000   0.7500E+02      +                                                 C
   0   0.000   1.000   0.8000E+02      +                                                 C
   0   0.000   1.000   0.8500E+02      +                                                 C
   0   0.000   1.000   0.9000E+02      +                                                 C
   0   0.000   1.000   0.9500E+02      +                                                 C
   0   0.000   1.000   0.1000E+03      +                                                 C
   0   0.000   1.000   0.1050E+03      +                                                 C
   0   0.000   1.000   0.1100E+03      +                                                 C
   0   0.000   1.000   0.1150E+03      +                                                 C
   0   0.000   1.000   0.1200E+03      +                                                 C
   0   0.000   1.000   0.1250E+03      +                                                 C
   0   0.000   1.000      INF          +                                                 C
 ---                                   +    +    +    +    +    +    +    +    +    +    +
 547                                   0        20        40        60        80        100
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
SYS5 DOWN TIME	0.1832E+02	0.1668E+02	0.9106E+00	0.0000E+00	0.6848E+02	547

1

HISTOGRAM NUMBER 18

SYS6 DOWN TIME

```
OBSV   RELA    CUML    UPPER
FREQ   FREQ    FREQ    CELL LIMIT   0         20        40        60        80        100
                                    +    +    +    +    +    +    +    +    +    +    +
  71   0.122   0.122   0.0000E+00   +******                                           +
  89   0.152   0.274   0.5000E+01   +********     C                                   +
  72   0.123   0.397   0.1000E+02   +******             C                             +
  67   0.115   0.512   0.1500E+02   +******                   C                       +
  48   0.082   0.594   0.2000E+02   +****                         C                   +
  43   0.074   0.668   0.2500E+02   +****                            C                +
  37   0.063   0.731   0.3000E+02   +***                                 C            +
  31   0.053   0.784   0.3500E+02   +***                                   C          +
  46   0.079   0.863   0.4000E+02   +****                                      C      +
  26   0.045   0.908   0.4500E+02   +**                                          C    +
  13   0.022   0.930   0.5000E+02   +*                                            C   +
  13   0.022   0.952   0.5500E+02   +*                                              C +
  16   0.027   0.979   0.6000E+02   +*                                               C+
   7   0.012   0.991   0.6500E+02   +*                                                C
   2   0.003   0.995   0.7000E+02   +                                                 C
   3   0.005   1.000   0.7500E+02   +                                                 C
   0   0.000   1.000   0.8000E+02   +                                                 C
   0   0.000   1.000   0.8500E+02   +                                                 C
   0   0.000   1.000   0.9000E+02   +                                                 C
   0   0.000   1.000   0.9500E+02   +                                                 C
   0   0.000   1.000   0.1000E+03   +                                                 C
   0   0.000   1.000   0.1050E+03   +                                                 C
   0   0.000   1.000   0.1100E+03   +                                                 C
   0   0.000   1.000   0.1150E+03   +                                                 C
   0   0.000   1.000   0.1200E+03   +                                                 C
   0   0.000   1.000   0.1250E+03   +                                                 C
   0   0.000   1.000      INF       +                                                 C
----                                +    +    +    +    +    +    +    +    +    +    +
 584                                0         20        40        60        80        100
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
SYS6 DOWN TIME	0.1914E+02	0.1740E+02	0.9094E+00	0.0000E+00	0.7445E+02	584

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